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Comprehensive Report on the KPEG (Potassium Polyethylene Glycolate) Process for Treating Chlorinated Wastes

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16. ABSTRACT

This comprehensive report describes the work performed in several laboratories toward the development of the alkali metal polyethylene glycolate (APEG) chemical dechlorination technology. The equipment and operational procedures implemented in various studies (ranging in scope from laboratory scale to full scale) are described and the results obtained are presented. Much of the work described herein was funded by the U.S. Environmental Protection Agency's Risk Reduction Engineering Laboratory, Cincinnati, OH.

The initial laboratory studies that were performed focused on treatment of oils that were contaminated with PCBs as well as closely related compounds, including polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs).

Laboratory-scale studies involving PCB-, PCDD-, and PCDF-contaminated soils were performed during the early to mid-1980's; the results of these studies led to the design and implementation of drum and pilot-scale versions of the APEG process. The largest APEG treatment system demonstrated to date consists of a steam-jacketed mixer, a steam-generating plant, and a condensate-collection system. On the Island of Guam, approximately 15 yds^3 of soil in batches of 1.5 to 2 yds^3 each (with average initial PCB concentrations of 3340 ppm) were treated with KPEG. The PCB concentrations in the Guam soil were reduced by more than 99 percent, with no individual PCB congener exceeding 2 ppm.

This report includes detailed information regarding the preparation of the contaminated soils prior to treatment; equipment and reagents used during treatment; and analyses performed before, after, and during treatment. The report provides the potential users of the APEG process with information that can be used to assess which version of the APEG process is best suited for implementation at a particular site.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

DISCLAIMER

This material has been funded wholly or in part by the United States Environmental Protection Agency under Contract 68-03-3413 to PEI Associates, Inc. It has been subject to the Agency's review and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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This comprehensive report describes the work performed in several laboratories toward the development of the alkali metal polyethylene glycolate (APEG) chemical dechlorination technology. The equipment and operational procedures implemented in various studies (ranging in scope from laboratory scale to full scale) are described and the results obtained are presented. Much of the work described herein was funded by the U.S. Environmental Protection Agency's Risk Reduction Engineering Laboratory, Cincinnati, Ohio.

The initial laboratory studies that were performed focused on treatment of oils that were contaminated with PCBs as well as closely related compounds, including polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). These early laboratory studies led to the design, construction, and use of a full-scale, fully portable system for treating PCB-, PCDD-, and PCDF-contaminated oil. This system, which was patented by Niagara Mohawk Power Corporation in 1985, has been used to treat several thousand gallons of contaminated oil.

Laboratory-scale studies involving PCB-, PCDD-, and PCDF-contaminated soils were performed during the early to mid-1980's; the results of these studies led to the design and implementation of drum and pilot-scale versions of the APEG process. The largest APEG treatment system demonstrated to date consists of a steam-jacketed mixer, a steam-generating plant, and a condensate-collection system. On the Island of Guam, approximately 15 yd^3 of soil in batches of 1.5 to 2 yd^3 each (with average initial PCB concentrations of 3340 ppm Aroclor 1260) were treated with KPEG. The PCB concentrations in the Guam soil were reduced by more than 99 percent, with no individual PCB congener exceeding 2 ppm.

This report includes detailed information regarding the preparation of the contaminated soils prior to treatment; equipment and reagents used during treatment; and analyses performed before, after, and during treatment. The report provides the potential users of the APEG process with information that can be used to assess which version of the APEG process is best suited for implementation at a particular site.

This report was submitted in fulfillment of U.S. Environmental Protection Agency (EPA) Contract No. 68-03-3389, Work Assignment No. 2-20, by PEI Associates, Inc. (PEI) under the sponsorship of the EPA. The field work was performed by PEI in Moreau, New York, and Guam, U.S.A., in fulfillment of EPA Contract No. 68-03-3413, Work Assignment No. 1-2, also under the sponsorship of the EPA. Funding for the work in Guam was also provided by U.S. Navy Interagency Agreement IAG RW 17933910.

CONTENTS

	Page
Foreword	iii
Abstract	iv
Figures	viii
Tables	ix
Abbreviations	xi
Acknowledgment	xii
1. Introduction	1
2. Conclusions and Recommendations	2
Conclusions	2
Recommendations	3
3. Background	4
Status of microbiological processes for PCB degradation	4
Summary of factors affecting PCB biodegradation	5
Current status of PCB biodegradation	6
Status of KPEG Chemical Dechlorination processes	6
4. Laboratory-Scale Studies	10
Franklin Research Center	10
Preparation of the NaPEG reagents	10
Description of contaminated matrices	10
Laboratory treatment	11
Results and discussion	11
University of Cincinnati	12
Description of contaminated matrices	12
Experimental procedures	12
Results and discussion	12
Wright State University	13
Phase I studies	13
Phase II studies	14
Phase III studies	15
5. Full-Scale Treatment of PCB-Contaminated Liquids	17
Butte, Montana: Laboratory-scale treatment	17
Description of contaminated matrix	17
Experimental procedures	17
Results and discussion	18
Butte, Montana: Full-scale treatment	18
Description of contaminated matrix	18
Field tests	18
Results and discussion	19
Kent, Washington: Full-scale treatment	19
Description of contaminated matrix	19
Field tests	20
Results and discussion	20

CONTENTS (continued)

		Page
6.	Bench-Scale Soil Treatability Studies	21
	Cloverdale, California	21
	Description of contaminated matrix	21
	Experimental procedures	21
	Results and discussion	21
	Guam, U.S.A.	22
	Description of contaminated matrix	22
	Experimental procedures	22
	Results and discussion	23
	Mechanicsburg, Pennsylvania	23
	Description of contaminated matrix	23
	Experimental procedures	23
	Results and discussion	23
7.	Drum-Scale Treatment	24
	Omaha, Nebraska	24
	Description of contaminated matrix	24
	Field tests	24
	Results and discussion	24
	Bengart & Memel, Inc., New York	25
	Description of site	25
	Field demonstration	25
	Results	28
8.	Field-Scale Soil Treatment	31
	Moreau, New York	31
	Description of site	31
	Description of process equipment	31
	Process operation and operating conditions	34
	Results	41
	Guam, U.S.A.	42
	Description of site	43
	Preparation of the soil for treatment	43
	Laboratory studies	46
	Field-scale KPEG system design	47
	Description of process equipment	47
	Preassembly and transport of KPEG system to Guam	54
	Process implementation	55
	Operation	58
	Storage of treated soil	59
	System decontamination and disassembly	59
	Treatment of collected condensate and decontamination water	60
	Analytical results	60
	Discussion of quality assurance and quality assurance goals	62
	Summary of QA/QC procedures used by IT-Knoxville for analysis of PCB samples from the Guam KPEG project	64

CONTENTS (continued)

	Page
Results obtained in quantitating polychlorinated dioxins and polychlorinated dibenzofurans	69
9. Cost Analysis of KPEG Process	71
KPEG treatment costs for the Guam demonstration	71
Projected full-scale KPEG treatment costs	73
Process description	73
Material and heat balances	78
Cost estimation	78
References	86
Appendix - Quality Assurance	89

FIGURES

Number		Page
1	Schematic of mobile field equipment	19
2	Central condenser system	27
3	Reactor detail	32
4	Equipment arrangement for the Moreau test	35
5	PCB concentration distribution (ppm), U.S. Naval Station, Public Works Center, Guam	44
6	Storage of PCB-contaminated soil and location of field-scale KPEG demonstration	45
7	Simplified mechanical flow diagram of KPEG field-scale treatment system	48
8	Layout of the Guam site showing locations of ancillary equipment	49
9	Detailed mechanical flow diagram of KPEG field-scale treatment system	50
10	Detailed site plan for KPEG field-scale treatment system	51
11	Design features of field-scale KPEG mixer	52
12	Flowsheet of scale-up KPEG process	76
13	Reactor batch size vs. treatment cost	85

TABLES

Number		Page
1	Phase I Percent Reduction From Initial TCDD Levels	14
2	Phase III Percent Reduction From Initial TCDD Levels	16
3	Percent Reduction in Starting TCDD Levels	16
4	Drum-Scale Treatment of TCDD, 2,4-D, and 2,4,5-T	24
5	Sample Group 1, Analyzed Only by EPA	28
6	Sample Group 2, Analyzed by EPA and GRC	29
7	Materials Charged to the Reactor	34
8	Detailed Reactor Contents	36
9	Reagent Recovered	36
10	Run 1--Operating Conditions	37
11	Run 2--Operating Conditions	38
12	Run 3--Operating Conditions	39
13	Run 4--Operating Conditions	40
14	Initial and Final Weights	41
15	PCB Concentrations Measured at the Site	42
16	Concentrations of PCBs Found in Pre- and Post-Treatment Guam Soils, Condensate, and KPEG Reagent, and Percentage Reductions Achieved for Soils	61
17	Quality Assurance Objectives for Precision, Accuracy, Completeness, and Method Detection Limits	65
18	Equipment Costs for 2-Ton KPEG Soil Treatment System Used in Guam Demonstration	72
19	Treatment Costs for 2-Ton Soil Treatment System Utilized for Guam Demonstration	74

TABLES (continued)

Number		Page
20	Process Flow Stream Composition and Temperature	79
21	Heating and Cooling Requirements	80
22	Estimated Equipment Cost for 25-Ton KPEG Soil Treatment Plant	81
23	Ratio Factor Used in Estimating Fixed Capital Investment for KPEG Process	83
24	Estimated Treatment Cost for KPEG Process	84
25	Breakdown of Treatment Cost	85

ABBREVIATIONS

Abbreviation	
APEG	Alkali metal polyethylene glycolate
DCBP	Dichlorobiphenyl
DCMA	Dry Color Manufacturers Association
DMSO	Dimethyl sulfoxide
EC/GC	Electron capture gas chromatography
EPA	United States Environmental Protection Agency
FRC	Franklin Research Center
GC	Gas chromatography
GCMS	Gas chromatography mass spectroscopy
GRC	Galson Research Corporation
h	Hour
HCB	Hexachlorobenzene
HCl	Hydrochloric acid
HCP	Hexachlorobiphenyl
HRGC/LRMS	High-resolution gas chromatography/low-resolution mass spectroscopy
H_2SO_4	Sulfuric acid
IT	International Technology Corporation
KOH	Potassium hydroxide
KPEG	Potassium polyethylene glycolate
NaOH	Sodium hydroxide
NaPEG	Sodium polyethylene glycolate
NCEL	Naval Civil Engineering Laboratory
NMPC	Niagara Mohawk Power Corporation
NYDEC	New York Department of Environmental Control
PCB	Polychlorinated biphenyl
PCDD	Polychlorinated dibenzodioxin
PCDF	Polychlorinated dibenzofuran
PCTP	Polychlorinated triphenyls
PEG	Polyethylene glycol
PEI	PEI Associates, Incorporated
ppb	Parts per billion (nanograms per gram)
ppm	Parts per million (micrograms per gram)
ppt	Parts per trillion (picograms per gram)
PWC	Public Works Center
QAPjP	Quality Assurance Project Plan
QA/QC	Quality assurance/quality control
RREL	Risk Reduction Engineering Laboratory
TCDD	Tetrachloro dibenzodioxin
THF	Tetrahydrofuran
TMH	Triethylene glycol methyl ether
UC	University of Cincinnati, Cincinnati, Ohio
USN	United States Navy
WSU	Wright State University, Dayton, Ohio
wt./wt.	Weight to weight

ACKNOWLEDGMENT

This report was prepared by PEI Associates, Inc., (PEI) Cincinnati, Ohio, as part of the work performed for the U.S. Environmental Protection Agency (EPA) Risk Reduction Engineering Laboratory (RREL) under EPA Contract No. 68-03-3413, Work Assignment No. 1-2. Mr. Charles J. Rogers and Mr. T. David Ferguson were EPA Technical Project Monitors.

Mr. Jack Greber served as Project Director for PEI for that portion of the work completed under EPA Contract No. 68-03-3413 (Work Assignment No. 1-2), and Mr. William Kemner served as Project Director for PEI for that portion of the work completed under EPA Contract No. 68-03-3389 (Work Assignment No. 2-20). Dr. Michael L. Taylor was Project Manager, and Mr. John A. Wentz was Assistant Project Manager. PEI performed two KPEG field demonstrations. Mr. William Gallagher was lead engineer during the work performed in Moreau, New York, and Mr. Wentz was lead engineer for the design, construction, and field evaluation of the KPEG treatment system in Guam. The diligence and dedication of PEI's field crew members is acknowledged.

The EPA program for developing the KPEG process was led by Mr. Charles J. Rogers, who was present in Moreau, New York, and Guam and provided assistance and guidance throughout the field studies. Mr. Rogers was assisted in EPA's laboratory and field studies by Dr. Alfred Kornel and Mr. Harold Sparks.

The evaluation of the KPEG process in Guam took place at the U.S. Navy (USN) Public Works Center (PWC). Dr. D.B. Chan of the Naval Civil Engineering Laboratory (NCEL) is acknowledged for his cooperation and assistance in coordinating U.S. Navy support. PEI is also grateful to Mr. Gorman Dorsey for the use of the USN PWC FENA laboratory on Guam, where onsite sampling analysis was performed, and to Mr. Jess Lizama, Supervisory Environmental Engineer of the USN PWC site, Guam, for arrangements of construction equipment, utilities, and USN PWC personnel assistance.

SECTION 1

INTRODUCTION

Certain halogenated organic compounds such as polychlorinated biphenyls (PCBs) and other related chemicals, including polyhalogenated dibenzo-p-dioxins (PCDDs) and polyhalogenated dibenzofurans (PCDFs), are widely known to be environmentally persistent and have been found to cause serious toxicological effects in man and especially in animals. The characteristic chemical stability of these halogenated aromatic compounds is the basis for their environmental persistence. Recently, however, several techniques have been devised that appear to be capable of destroying these persistent haloorganics. These degradative processes include incineration at high temperature, ultraviolet (UV) photolysis, chemical degradation, and potentially microbiological degradation.

This report provides a comprehensive discussion of a chemical dechlorination process, which uses alkali metal polyethylene glycolate (APEG) to effect the dechlorination of PCBs, PCDDs, and PCDFs. For added perspective, the status of microbiological processes for degrading PCBs is briefly addressed.

Section 2 contains the conclusions and recommendations regarding potassium polyethylene glycolate (KPEG) that have been formulated based on this report. Section 3 presents the background information pertinent to the status of microbial methods for degrading PCBs and the development of chemical dechlorination methods for treating PCBs. Section 4 presents an overview of laboratory-scale KPEG studies. Section 5 discusses full-scale treatment of PCB-contaminated liquids. Section 6 presents an overview of laboratory-scale soil KPEG treatability studies. Section 7 discusses drum-scale treatment of soil. Section 8 provides details of the full-scale KPEG treatment of PCB-contaminated soils at the Moreau, New York, site and on the Island of Guam, U.S.A., and Section 9 presents an economic analysis of this treatment.

With the exception of the KPEG field demonstrations performed at the sites in Moreau and Guam, the information presented herein was provided to PEI Associates, Inc. (PEI) by the U.S. Environmental Protection Agency (EPA), primarily in the form of internal reports not previously presented in the open literature.

PEI, with the assistance of Dr. A. Kornel of EPA, has extracted and summarized the data contained in these unpublished documents. As the prime contractor for the studies performed at Moreau and Guam, PEI has first-hand knowledge of these studies.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

Man-made synthetic compounds designed to be resistant to degradation, PCBs have been used for more than 50 years as transformer oils, capacitor dielectrics, heat-transfer fluids, hydraulic fluids, and in other similar applications. They have, however, been reported to cause dermatitis, liver disease, and possibly carcinoma. Because of the numerous concerns regarding PCBs, their removal from our environment is desirable.

Large quantities of PCB oils and soils contaminated with these compounds exist in the environment. Biodegradation of PCBs and related or similar compounds would provide a relatively simple mechanism for their elimination. Several biodegradation studies have been performed on PCBs in oil and soil, however, with results that have not been totally satisfactory. Although higher chlorinated PCBs have been found to be resistant to biodegradation by naturally occurring microorganisms, some biodegradation studies have shown that some microbial strains are capable of degrading low percentages of specific PCB isomers under carefully controlled laboratory conditions. In situ studies have not yielded promising results, however.

In 1978, a chemical reagent was identified at the Franklin Research Center (FRC) in Philadelphia, Pennsylvania, that was capable of physically altering the PCB molecule and yielding a byproduct that appears to be less hazardous. Since that discovery, investigations into the applicability of the chemical dechlorination technology have been conducted in the laboratory and the field with encouraging results. The studies that have been performed have involved the destruction of PCBs in oil and soil.

Initial studies were performed to identify the most effective reagent formulations for degrading PCBs in oil. The results from the initial studies indicated that the potassium polyethylene glycolate (KPEG) reagent was superior to sodium polyethylene glycolate (NaPEG) for the destruction of PCBs in oil and that water had an adverse effect on the rate of contaminant destruction. In 1985, a full-scale, trailer-mounted, fully portable KPEG treatment system for PCB oil was constructed. By October 1987, more than 6000 gallons of transformer oil and 20,000 gallons of dioxin-contaminated waste oil had been successfully treated with this unit. The results achieved with the full-scale KPEG chemical dechlorination process for PCB/dioxin-contaminated oil were encouraging and provided additional impetus to the investigation of the applicability of the KPEG chemical dechlorination process for soils contaminated with PCBs and other halogenated aromatic compounds.

The EPA extensively investigated the efficacy of the chemical dechlorination technology for treating soils contaminated with PCBs and other similar contaminants, and numerous laboratory, bench, and field pilot studies have been performed. The process has been found to be potentially applicable for decontaminating soils contaminated with compounds such as PCBs (Aroclor 1242, 1248, 1260), polychlorinated triphenyls (PCTPs), 2,4-D, 2,4,5-T, 2,3,7,8-TCDD, and other similar compounds. The KPEG process was scaled up and used to treat between 1.5 and 2.0 yd^3 of PCB-contaminated soil per batch in a remote location on the Island of Guam, U.S.A. Results from this demonstration proved that the technology was amenable to scaleup and that the pilot-scale equipment could be transported over long distances and used at remote sites. The Guam soil was contaminated with an average of 3430 ppm of Aroclor 1260; after treatment with KPEG, the PCBs were reduced by more than 99 percent, with no individual PCB congener exceeding 2 ppm.

2.2 RECOMMENDATIONS

The laboratory-, bench-, and field-scale KPEG chemical dechlorination studies performed to date on oils and soils contaminated with chlorinated aromatic compounds have been very successful. It is appropriate to test the technology for its applicability to other types of contaminated matrices, such as various types of sludges that may be located at existing or abandoned industrial facilities. Although the toxicological testing that has been performed to date indicates that the KPEG-treated residues are not dangerous, additional work is required to assess the toxicological properties of complex mixtures (e.g., soil/hydrocarbon mixtures) that have been treated with KPEG. In addition, the identity and chemical properties of the actual degradation products should be determined to obtain data in support of delisting of KPEG-treated products.

Recommendations can be summarized as follows:

1) Evaluate further the byproducts of the treatment process to determine their identity, environmental fate, and toxicology. Proceed to gain EPA approval for final disposition of treated soil.

2) Inasmuch as currently available data indicate the byproducts appear to be benign, continue development of the KPEG technology:

   a) Scale up to full scale and put into operation an economical KPEG system capable of treating oils and excavated soils.

   b) Initiate studies on the application of the chemical degradation technology for in situ treatment of contaminated soils that have not yet been excavated.

3) Investigate the utility of KPEG in "treatment trains" in which two or more processes are used for sequential treatment of contaminated wastes.

SECTION 3

BACKGROUND

Chemical compounds that contaminate liquid or soil matrices at abandoned waste sites threaten public health and safety and endanger water resources through erosion or leaching into the ground water. The presence of highly toxic and hazardous chemicals on the ground can also severely limit land use. For example, the accumulation of wastes containing toxic chemicals such as PCBs, PCDDs, and PCDFs in the environment poses a crucial problem that should be carefully evaluated and resolved.

Polychlorinated biphenyls are nonflammable low-volatility materials that have excellent heat stability and good viscosity characteristics at elevated operating temperatures. These compounds were used as transformer oils and heat-exchanger oils in electrical equipment and at powerplants. Because PCB products are toxic to human health and the environment, however, their continued manufacture, import, and use in newly manufactured devices were prohibited in the United States under the Toxic Substances Control Act of 1976. Since July 1, 1979, EPA regulations have stipulated that any material containing more than 50 ppm of a mono-, di-, or polychlorinated biphenyl is considered as PCB-contaminated material and must be disposed of by incineration in an approved manner or at an approved landfill. Incineration or landfilling, however, have usually proved to be unacceptable by the people living near the disposal areas; therefore, alternative techniques for degrading PCBs are much needed.

3.1 STATUS OF MICROBIOLOGICAL PROCESSES FOR PCB DEGRADATION

Several different methods have been considered for the destruction of PCBs in wastes; among these is the use of live organisms for the biodegradation of this compound. Biodegradation is defined as molecular degradation of organic substances due to the complex action of living organisms. The controlled destruction of hazardous materials by natural methods in biological treatment has been investigated for the treatment of PCB-contaminated soils.

In 1975, Bourquin and Cassidy reported that the growth of Florobacterium, Bacillus, Corynebacterium, Pseudomonas, Achromobacter, Micrococcus, and Serratia isolated from a Florida estuary was inhibited by Aroclor 1242. Another study (Keil et al. 1972) concluded that the increase in population of Escherichia was accelerated by Aroclor 1242. Results obtained from the study by Wong and Kaiser (1975), however, indicated that Aroclors 1221, 1242, and 1254 did not stimulate the growth of bacteria isolated from lake water.

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These various studies on the biodegradation of PCBs did not produce definitive and uniform results. In a 1973 study by Amed and Focht, the biodegradability of several mono- and dichlorobiphenyls by Achromobacter was researched, and chlorobenzoic acids were identified as degradation products. Baxter et al. (1975) demonstrated that dichlorobiphenyls were successfully degraded by Nocardia and Pseudomonas. The degradation of tetrachlorobiphenyls during their study, however, was very limited.

Research conducted on tetrachlorobiphenyls and 2,4,5,2',5'-pentachlorobiphenyls (Furukawa and Matsumura 1976) indicated a slight degradation of these materials by the Alcaligenes species. Throughout this study, the researchers also noticed that substituted X-hydroxy muconic acids act as the biodegradation intermediate during the biodegradation process.

Unterman et al. (1987) reported that bacterial isolates such as Corynebacterium (MBI), Alcaligenes entrophus H850, and Pseudomonas Putida (LB400) have excellent PCB-degradation capabilities under laboratory assay conditions. They also evaluated several contaminated matrices, including PCB-spiked sand, "clean" soil, and actual contaminated soil samples from the site of a former racing dragstrip. The soil samples contained 525 ppm of transformed Aroclor 1242, which is depleted to di- and trichloro-biphenyls and therefore appears similar in composition to Aroclor 1248. The results obtained from an in situ biotreatment approach for contaminated soils indicated that approximately 25 percent of the PCBs in the soils were destroyed.

Furukawa (1982) studied the microbial degradation of PCBs in the environment and concluded that the following factors affect the process:

1) Physical and chemical nature of components: Degree of chlorination, position of substituted chlorines on the biphenyl molecule, and water solubility and volatility.

2) Microbial aspects: Occurrence and distribution of PCB-degrading organisms, and their ability for PCB degradation.

3) Environmental factors: Photolysis by sunlight, pH, temperature, oxygen, nutrition, and absorption of PCBs by such materials as soil, sediment, sludge, and biological matter.

3.1.1 Summary of Factors Affecting PCB Biodegradation

Based on the data available in the literature, several factors apparently affect the biodegradation of PCBs:

- The rate of PCB biodegradation is affected by temperature. Studies have indicated that biological processes have increased exponentially with an increase in temperature in the range of 5° to 30°C.

- Oxygen molecules are required for the breakdown of aromatic chemicals and the dechlorination of some chlorinated compounds.

- The rate of PCB destruction by degrading bacteria is slow in the uncontrolled in situ application of microbes, whereas laboratory studies have demonstrated a significant increase in degradation of these contaminants under controlled reactor conditions.

- Because PCB contaminants are not a natural product, the ability of naturally occurring microorganisms to degrade them is limited.

- Neutral pH ranges are required for maximum activity and diversity of microorganisms.

- Nitrogen and phosphate must be available for the growth of the indigenous or inoculant population of the microorganisms.

3.1.2 Current Status of PCB Biodegradation

The biological treatment of wastes containing PCBs is difficult because many PCB isomers are highly chlorinated and therefore not easily attacked by microorganisms. Nevertheless, studies have indicated that some microbial populations can biologically degrade some PCBs in waste material. The biodegradation of PCBs is currently being investigated, and factors affecting organism viability, establishment, competition, and rate of degradation must be studied further to develop techniques that can be applied in the field.

3.2 STATUS OF KPEG CHEMICAL DECHLORINATION PROCESSES

The chemical dechlorination methods described in the remainder of this report represent treatment/disposal alternatives to the biological treatment of PCB-contaminated wastes. Some of these process techniques appear quite promising.

A technique suggested by D. K. Parker et al. (1980) entails a lengthy multistep procedure that involves the formation of a solution of an organosodium reagent (i.e., sodium naphthalenide) in a carrier solvent such as tetrahydrofuran and the incorporation of this reagent into the PCB-contaminated oil. At least 2 hours later, the process is completed by water quenching and the recycling of the tetrahydrofuran.

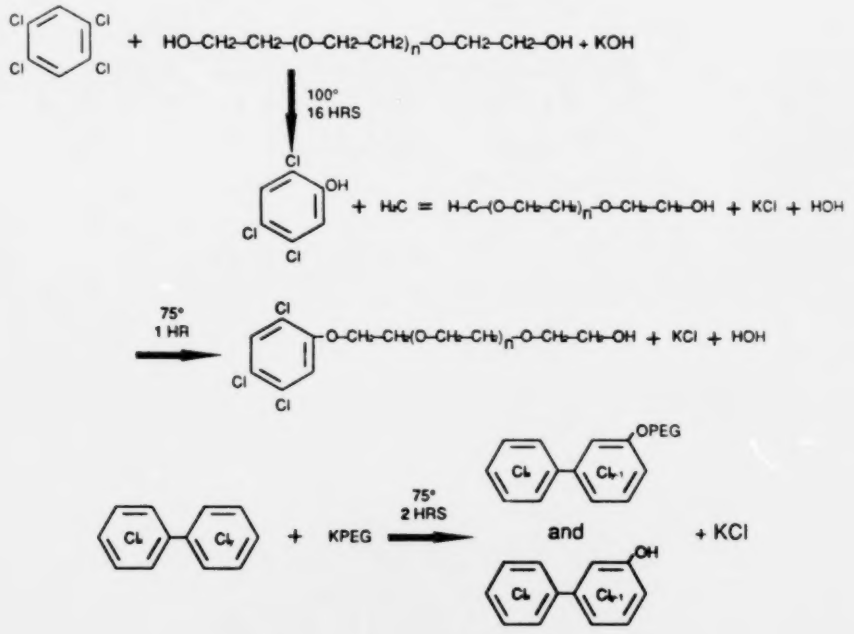
Another technique, proposed by Smith et al. of the University of Waterloo, involves the use of sodium naphthalenide for the chemical destruction of PCBs. This lengthy multistep procedure is similar to the preceding procedure suggested by Parker et al.

At the Chemistry and Biosciences Lab, FRC, Philadelphia, Pennsylvania, in the summer of 1978, a chemical reagent was synthesized and found to destroy PCBs (Iaconianni 1984). Since that time, a group of reagents, which are essentially APEGs, have been developed and are known as NaPEG reagents. These reagents effectively dehalogenate haloorganic compounds in a short period of time. Because of this success, the use of a NaPEG reagent was promptly considered for treating PCB-contaminated material.

In August 1979, the EPA provided FRC with a grant for investigation of the dechlorination of PCBs. The research was completed and described in a Project Report entitled "Dehalogenation of PCB's Using New Reagents Prepared From Sodium Polyethylene Glycolate - Application to PCB Spills and Decontaminated Soils," dated August 31, 1982. The EPA then provided another grant to FRC in 1982 for investigation of the effects of variable reaction parameters on the rate and extent of chemical decontamination of the substrate. The research concentrated exclusively on treating PCB-contaminated soils with chemical reagents.

Laboratory experiments with actual soils spiked with PCBs have shown that water in the soils greatly reduces the ability of a NaPEG reagent to dechlorinate PCBs. While the NaPEG research was being continued, a KPEG reagent was also developed, and investigations were conducted on the efficiency of this reagent for destroying PCBs. Studies indicate that KPEG is at least two times more reactive in the PCB destruction process than is NaPEG, and it is less sensitive to water (FRC 1982).

Brunelle (1983) published two articles describing chemical dechlorination studies performed at General Electric. Brunelle found that a variety of thiolates (formed via the reaction of an alkali metal with an aromatic or alkyl thiol) could, in the presence of one of several phase-transfer catalysts, react with the PCBs comprising Aroclor 1254 and degrade up to 95 percent of the Aroclor. Brunelle also focussed on the reaction of KPEG and NaPEG with halogenated aromatics and reported that, under mild conditions (75°C), the glycolates could react with Aroclor 1260 to cause up to 92 percent degradation of the Aroclor. The reactions described by Brunelle are depicted below:



The preceding reactions indicate that the products that Brunelle reports to result from the reaction of PCBs with KPEG are the corresponding glycolate ether, which is formed when a nucleophilic displacement of chlorine occurs. Apparently, a degradation of this ether can also occur and lead to the formation of a chlorobiphenyl and an ethylene derivative of polyethylene glycol (PEG). Brunelle secured a patent for this process (Brunelle 1982).

Brunelle (1983) also reported the results of toxicological evaluations of residues resulting from KPEG treatment of Aroclor 1260. The glycol phase resulting from treatment of Aroclor 1260 gave no evidence of oral toxicity in rats at 5000 mg/kg, produced no toxicity through dermal absorption in a mouse, and caused only mild eye irritation in a rabbit.

In 1984, Klee et al. (1984) published a report that indicated that the KPEG process is applicable for the treatment of soils contaminated with 2,3,7,8-TCDD. These soils were obtained from a farm in Missouri where contaminated residues from a 2,4,5-trichlorophenol manufacturing operation were buried.

Kornel and Rogers (1985) have published a report that compares the rates of dechlorination achieved under various conditions. This paper reports that appreciable PCB degradation can occur even when the APEG reagent is diluted 50 percent with water.

In 1982, Niagara Mohawk Power Corporation (NMPC) developed a process for the removal and destruction of PCBs in transformer oils. The process used a low-toxicity, low-hazard reagent to dechlorinate PCBs that were no longer soluble in the original oil. In 1985, EPA Region II and the New York Department of Environmental Control (NYDEC) granted a mobile PCB treatment permit to NMPC to conduct a full-scale demonstration of a treatment rig. As of October 1987, more than 6000 gallons of transformer oil and 20,000 gallons of dioxin-contaminated waste oil had been successfully treated under different contracts. The reagent for the oil-treatment process consisted of potassium hydroxide (KOH) and a mixture of liquid reagent materials. As a means of improving the rate of contaminant extraction from the oil phase, sulfoxides (i.e., dimethyl sulfoxide) or sulfolane and amines (i.e., ethylene diamine) also were added to the hydroxide/alcohol mixture. In the laboratory testings, these cosolvents substantially increased the reaction rates.

The Goodyear Tire and Rubber Company developed a PCB destruction process that has reduced concentrations of PCBs in heat-transfer fluids from greater than 500 ppm to less than 10 ppm (des Rosiers 1987). The reagent is formed by using metallic sodium and mixing it with a dispersing oil at 150° to 170°C. The oil is then cooled and mixed with the solvent tetrahydrofuran (THF) and naphthalene. The reagent is then mixed with the PCB-contaminated fluids at a reagent-to-chlorine ratio of 50 to 100:1 under a nitrogen blanket.

Sun Ohio developed and patented a process that reduced the concentration of PCBs in transformer oils from 225 to 1 ppm (des Rosiers 1987). This

trailer-mounted, mobile process is highly applicable for treating contaminated material having low levels of PCB contamination. The process was used successfully to treat 163,000 gallons of PCB-contaminated oils at Maxwell Laboratories in San Diego, California, and 5250 gallons of oil initially contaminated with 420 to 1500 ppm PCBs at Chevron in El Segundo, California.

In 1980, Acurex Company developed a dechlorination process that has reduced a PCB concentration ranging from 1000 to 10,000 ppm to a concentration of less than 1 ppm. Studies have indicated that the application of this method has actually reduced concentrations of 2,3,7,8-TCDD in transformer oil from 200 to 400 ppt to 20 to 60 ppt.

In 1985, Peterson et al. at Galson Research Corporation (GRC) of Syracuse, New York, developed a PCB destruction method in conjunction with the EPA. This method demonstrated that chlorinated biphenyls and dioxins could be decomposed and removed from soils. A reagent consisting of a mixture of glycol, alkali metal hydroxide, and dimethyl sulfoxide was used to reduce the dioxin concentrations from 2000 ppb to less than 1 ppb in a short period of time. This process requires the formation of alkoxide from a combination of potassium hydroxide and PEG. The alkoxide then reacts with the PCB or dioxin and removes the chlorine atoms, which results in the formation of a salt. Peterson (1986) was granted a patent for a KPEG process for treating soils.

Vertac Chemical Corporation developed a treatment process that promotes the successful destruction and removal of 2,3,7,8-TCDD and other chlorinated dioxins (des Rosiers 1987). This process involves the use of anhydrous alkali metal salts of polyhydroxy alcohols to dechlorinate dioxins at atmospheric pressure. Furthermore, a mixture of chlorinated dioxins, an alcohol, and a water solution of an alkali metal hydroxide can accomplish dechlorination. Experiments conducted on contaminated material containing concentrations of 2,3,7,8-TCDD as high as 250-ppm, showed that this technique could accomplish 99.95 percent destruction of this compound.

In 1989, DeMarini and Simmons published results of toxicological investigations in which the residues from KPEG treatment of 2,3,7,8-TCDD were reported to exhibit no mutagenic or toxicological effects.

SECTION 4

LABORATORY-SCALE STUDIES

4.1 FRANKLIN RESEARCH CENTER (FRC)

In this EPA-sponsored study (Iaconianni 1985), the effectiveness of APEG reagents for degrading PCB (Aroclor 1260) in soil was assessed at the laboratory scale. The study was conducted during 1980 through 1984 at FRC in Philadelphia, Pennsylvania.

4.1.1 Preparation of the NaPEG Reagents

The NaPEG reagents used in the laboratory experiments were prepared in FRC's laboratory. All formulations of this reagent are referred to as "NaPEG™ reagents," including those containing potassium. Specific reagents, such as "KPEG 350-1," retain the proper alkali metal nomenclature, whereas NaPEG reagent is a general term. The specific reagents were prepared as follows:

KPEG-350 - Prepared from equimolar quantities of potassium metal and polyethylene (glycol monomethyl ether); average molecular weight 350 (PEG-350).

KPEG-350-1 - Prepared from equimolar quantities of potassium hydroxide and PEG-350.

KPEG-400-1 - Prepared from equimolar quantities of potassium hydroxide and PEG-400.

NaPEG-400-N - Prepared from equimolar quantities of sodium metal and PEG-400 under nitrogen.

NaPEG-350-1 - Prepared from equimolar quantities of sodium hydroxide and PEG-350.

4.1.2 Description of Contaminated Matrices

Soils were collected from three sites for use in the study at Franklin Research Center. These were as follows:

1) A sample of sandy soil was obtained from an uncontaminated site in New Jersey and spiked with Aroclor 1260 to a level of approximately 1000 ppm.

2) Samples weighing approximately 50 to 100 grams were obtained from various depths at the Bengart & Memel site in Buffalo, New York. This soil was contaminated with PCB (Aroclor 1260).

3) Two 5-gallon cans of soil and stone were obtained from Brown-Boveri, Inc., in Philadelphia. The contents of the two cans were combined, thoroughly mixed, and then passed through a 3/8-inch mesh screen to eliminate large stones. When analyzed, the soil was found to contain 14.5 percent H_2O and 1150 ppm Aroclor 1260.

4.1.3 Laboratory Treatment

The soil samples were each treated by the addition of 10 percent (wt./wt.) of the various NaPEG and KPEG reagents. The quantity of soil sample treated per batch varied from 100 to 500 grams. The reaction occurred at room temperature, and the reaction time varied from 1 to 180 days. After the reaction was completed, the reaction mixture was neutralized with sulfuric acid.

Gas chromatography with electron-capture detection (GC-ECD) was used for the quantitative determination of PCBs in soils. Duplicate samples of both treated and untreated soils were analyzed for PCBs. The concentration of PCB was expressed in parts per million based on the weight of extracted dried soil.

4.1.4 Results and Discussion

4.1.4.1 PCB-spiked soil--

The results showed that a soil containing 1000 ppm of Aroclor 1260 can be decontaminated (to below 50 ppm PCB) in only a few days by a direct application of KPEG-350-1. Particularly encouraging was the fact that this reagent can be used on soil containing some moisture and organics and that the reagent continues to react with PCBs after several days in open air. The NaPEG-400-N reagent was not as effective as the KPEG-350-1 reagent. From increasing to decreasing reactivity, the reagents are ranked as follows: KPEG-350-1 > NaPEG-350-1 > NaPEG-400-1.

4.1.4.2 Brown-Boveri Soil--

The results obtained when this soil was treated with a NaPEG reagent indicated that the reagent was not able to reduce the PCB content in a wet soil. It was also found that increasing the soil temperature (80° vs. 65°C) had a positive effect in reducing the PCB concentration. An increase in the amount of time alotted for the reaction to occur resulted in a continued decrease in the amount of PCBs in the soil, particularly the more halogenated isomers.

4.1.4.3 Bengart & Memel Soil--

The untreated and field-treated Bengart & Memel soil repeatedly showed significant reductions in PCB concentration after the NaPEG treatment in the laboratory. In some cases, the concentration of PCBs in the field-treated

soils was determined to be higher than that in the control soils. For example, the concentration of the PCBs with lower retention times was generally significantly higher in the treated soils.

The field-treated samples that were subsequently treated in the laboratory showed some dechlorination, usually in 1 to 5 days. After that, the reaction rate slowed so that the level of additional dechlorination was insignificant by the 18th day. Under similar laboratory conditions, the soil from the Brown-Boveri site, which had not been previously treated on site, showed a greater reduction in the PCB level in less time.

4.2 UNIVERSITY OF CINCINNATI

The goals of this 1983 EPA-sponsored study (Macomber 1983) performed by the Department of Chemistry at the University of Cincinnati (UC) in Cincinnati, Ohio, were as follows:

1) To determine whether PEG reagents react with PCBs and related compounds.

2) To identify the most reactive PEG-based reagent in this context.

3) To ascertain the effect of experimental variables (dilution, air, water, temperature, etc.) on the efficiency of these reagents.

4) To investigate the structure of the products of these reactions.

4.2.1 Description of Contaminated Matrices

The haloaromatics hexachlorobenzene (HCB), 4,4'-dichlorobiphenyl (4,4'-DCBP), hexachlorophene (HCP), and Aroclor 1254 were used in neat form in all of the reactions studied.

4.2.2 Experimental Procedures

Two basic types of reagents (hydrated and anhydrous) were prepared. The hydrated reagents were prepared by reacting concentrated aqueous NaOH or KOH with PEG-400. The anhydrous reagents were prepared by reacting excess PEG-400 with molten sodium or potassium metal.

A weighed sample of chlorinated aromatic substrate was added to a weighed sample of freshly prepared reagent, and the mixture was then stirred under argon gas. In most experiments, the reagent was present in tenfold excess. The neat organics were used in quantities ranging from 0.100 to 1200 milimoles. The temperature of the reaction mixture was controlled by a thermostated oil bath. The temperature of the experiments varied between 25° and 140°C, and the reaction time varied from 1 to 90 hours.

4.2.3 Results and Discussion

The anhydrous PEG reagents effectively dechlorinated HCB and converted it to water-soluble products. Workers reported that the substrate reactivity

was drastically reduced as the number of chlorine substituents decreased. Dissolving the reagents in toluene improved their reactivity, whereas the presence of air or water decreased their reactivity. If excess water was added to the reagent, phase separation occurred and the reagent's reactivity decreased even further, as the base took the form of concentrated aqueous alkali hydroxide.

With regard to dioxin contamination, the nearest model substrate was HCP, which was not affected by KPEG/toluene. Dioxin with only two chlorines per ring and two electron-releasing oxygens probably would not react with PEG-based nucleophiles. (These authors did not comment on whether higher chlorinated dioxins would react.)

Of the chlorinated substrates studied, the reactivity order (maximum chlorides released per molecule) was as follows: HCB (4.5) >> Aroclor 1254 (1.3) >> 4,4'-DCBP (0.2) > HCP (0).

4.3 WRIGHT STATE UNIVERSITY

This research was conducted by the U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory (IERL), Cincinnati, Ohio, in conjunction with Wright State University (WSU), Dayton, Ohio, to determine the abilities of alkaline mixtures of polyethylene glycols to degrade 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) in two samples from Missouri (Klee et al. 1984).

In these studies, a variety of alkali metal polyethylene glycolates were employed and are described below:

- K-120 - A reagent prepared by reacting potassium (metal or hydroxide) with polyethylene glycol having an average molecular weight of 120.
- K-400 - A reagent prepared by reacting potassium (metal or hydroxide) with polyethylene glycol having an average molecular weight of 400.
- KM-350 - A reagent prepared by reacting potassium (metal or hydroxide) with a monomethyl polyethylene glycol ether having an average molecular weight of 350.

The WSU studies were performed during three consecutive phases and the results obtained during each of the three phases are presented in the following subsections.

4.3.1 Phase I Studies

Two APEGs were involved in the first phase of these studies: 1) K-400, and 2) K-120. These reagents were used both with "neat" solutions of 510 nanograms TCDD (i.e., solutions containing TCDD dissolved in toluene; no soils were present) and with two types of Missouri soils: 1) Denny Farm,

and 2) Timberline Stables. The organic chlorine contents of these two soils were, respectively, 1380 ppm and 15.3 ppm; their TCDD contents were, respectively, 330 (±33 ppb) and 277 (± 28 ppb). The results of these tests were as follows:

1) With regard to the neat solutions, the K-120 destroyed virtually all of the TCDD within a 2-day period. The results with K-400, however, were indeterminate because the reagent was not miscible with the toluene solution of TCDD.*

2) The percent reductions in TCDD from the original levels in the soil samples are shown in Table 1.

TABLE 1. PHASE I PERCENT REDUCTION FROM INITIAL TCDD LEVELS

No. of days	Timberline Stables		Denny Farm	
	K-400	K-120	K-400	K-120
7	45	46	nm[a]	51
28	35	38	12	5

[a] nm = Not measured.

The TCDD reduction data varied cyclically throughout the 4 weeks of the tests, with the samples showing an anomalous final TCDD reduction, at 28 days, lower than that observed after 7 days. Furthermore, the variability of replicate analysis was quite high; in some cases the variability, expressed as a coefficient of variation, was as high as 40 percent.

4.3.2 Phase II Studies

It was decided to conduct a series of supplementary experiments, which involved alterations in sample preparation and in analytical procedure, to try to discover the source of this high variability and perhaps an explanation for the anomalous 7- versus 28-day results. The experiments conducted, and the results, are summarized as follows:

1) There was no statistical evidence that exhaustive Soxhlet extraction, even with fresh solvent and with extraction times of up to 32 hours, extracted more TCDD than bottle extraction with extraction times of no more than 3 hours.

2) Although statistically significant differences do exist between "unconditioned" and "conditioned" soils (by "conditioning" is meant

* The K-400 reagent used in Phase I was prepared using a 66 percent aqueous KOH solution and therefore was not miscible with toluene.

the addition of HCl, potassium hydroxide, or polyethylene glycol to the soil sample, followed by analysis for TCDD), the size of these differences is relatively unimportant. The following averages illustrate the differences found (the glycol used had an average molecular weight of 400 and is referred to as "PEG-400" in the listing below):

Unconditioned:	292 ppb
With HCl:	302 ppb
With KOH:	313 ppb
With PEG-400:	317 ppb

Thus, neither the individual components of the reagent itself nor the quench chemical used in the analytical procedure (i.e., the HCl) appreciably affects the amount of TCDD released from a soil sample during analysis. Furthermore, this observation is valid regardless of the period of time, up to 8 hours, that the chemicals are in contact with the soil.

3) There is no measurable time effect, up to 8 hours, on the recovery of the internal standard (37-Cl-labeled) after addition to the sample. Thus the amount of time (up to 8 hours) that samples stand after the internal standard is added does not affect the precision of the results.

4) During these supplementary experiments, the precision of the analysis increased dramatically over that observed in the first series. Since the soil samples in the supplementary series were considerably more homogeneous than in the first (in the supplementary series the samples were sieved, intermixed, and ground in a ceramic ball mill containing Borundum grinding media; in the first series the samples were sieved and intermixed only), it was concluded that inadequate sample preparation was the main cause of the anomalous results shown in Table 1. It is now clear that the TCDD is not presently uniformly distributed throughout the soil samples and therefore it is imperative that soil samples be thoroughly homogenized before they are subjected to treatment with APEG reagents in laboratory studies.

4.3.3 Phase III Studies

As a consequence of these supplementary studies, a third (and last) series of experiments was conducted that essentially was designed as a repetition of Phase I. During the interim between Phase I and Phase III of this study, however, new APEG reagents were tested that appeared to be much more reactive than K-120. Thus, K120 was replaced by one of these new reagents, i.e., KM-350, in this last phase. In addition, the K-400 reagent used in Phase III was prepared directly from KOH pellets, rather than the 66 percent aqueous KOH solution used in Phase I. Only Denny Farm soil was used in the Phase III experiments. The results are shown in Table 2 (in percent reduction in TCDD from the original level in the Denny Farm soil).

TABLE 2. PHASE III PERCENT REDUCTION FROM INITIAL TCDD LEVELS

No. of days	Denny Farm soil	
	K-400	KM-350
1	8	15
7	19	27
14	16	36
21	25	42
28	22	43

The anomalies in the apparent decrease of the TCDD level of the K-400 treated sample at Day 14 were not found to be statistically significant.

To test the effect of a multiple application of the APEG reagent, a sample of Denny Farm soil was treated with K-400 and, 12 days later, a second application was made. Table 3 summarizes the percent reduction in TCDD observed, along with a repetition of Days 14 and 21 in the single-application data of Table 2 for comparison.

TABLE 3. PERCENT REDUCTION IN STARTING TCDD LEVELS

No. of days	Denny Farm soil treated with K-400	
	Single application	Repeat application
14	16	56
21	25	68

The results of this study clearly indicate that APEG reagents can, under certain laboratory conditions, significantly reduce the levels of TCDD in contaminated soils.

SECTION 5

FULL-SCALE TREATMENT OF PCB-CONTAMINATED LIQUIDS

5.1 BUTTE, MONTANA: LABORATORY-SCALE TREATMENT

The purpose of this laboratory-scale study was to demonstrate the effectiveness of the KPEG process in degrading PCDD and PCDF isomers contained in oil samples (with percent levels of pentachlorophenol) from a Butte, Montana, site. The study was conducted in 1986 at Brehm Laboratory at Wright State University in Dayton, Ohio, under EPA contract (Tiernan 1987).

5.1.1 Description of Contaminated Matrix

The contaminated oil contained 3 to 5 percent pentachlorophenol, PCDD, and PCDF homologs ranging from 422 ppb of tetrachlorinated isomers to 83,923 ppb of octachlorinated isomers.

5.1.2 Experimental Procedures

A KPEG reagent formulation made of PEG, KOH, and dimethyl sulfoxide (DMSO) was used for these tests. Two 500-g samples (a waste oil sample and a contaminated soil sample) were obtained from the site. The procedures used for the treatment of the oil samples with the KPEG reagents are described herein.

Two 25-g aliquots of oil were removed from the 500-g sample and were accurately weighed into new, precleaned, 125-ml glass bottles fitted with Teflon-lined caps. A reagent blank bottle was simultaneously prepared. Twenty-five grams of the KPEG reagent was added at ambient temperature to each of these three bottles. The bottles were placed in sand baths maintained at temperatures of 70° and 100°C for 8 hours. The contents of each bottle was stirred with a motor-driven stirring rod during this entire period.

Accurately weighed aliquots (typically 1 to 5 g) of each treated sample were removed from each bottle at 15-minute intervals and placed in 125-ml flint glass sample bottles. The reaction was stopped by adding enough 50 percent sulfuric acid (H_2SO_4) to each sample bottle to adjust the pH to about 7, as determined by indicator paper. After the neutralization of the treated samples, the bottles were set aside until test portions could be successfully extracted and analyzed.

5.1.3 Results and Discussion

After the oil samples from the Butte, Montana, site had been treated with the KPEG, they were extracted and the resulting extracts were analyzed by gas chromatography/mass spectroscopy (GC/MS) to determine if PCDDs and PCDFs had been destroyed. The experimental results showed that many of the congeners of PCDD and PCDF were destroyed effectively by the KPEG when the temperature was as low as 70°C for 15 minutes. All PCDD and PCDF congeners were completely destroyed by KPEG when the sample was heated to 100°C for 30 minutes. Because of these successful laboratory tests, arrangements were made to lease equipment for full-scale treatment of the remaining oil stored on the site.

5.2 BUTTE, MONTANA: FULL-SCALE TREATMENT

In 1986, a full-scale version of the KPEG process (built by NMPC and operated by IT Corp.) was evaluated to determine if a chemical reagent prepared from potassium hydroxide and polyethylene glycol could be used to treat PCDD- and PCDF-contaminated oil at an industrial wood-preserving site near Butte, Montana (des Rosiers 1987).

5.2.1 Description of Contaminated Matrix

The wood-preserving site contained approximately 9000 gallons of light petroleum oil that had previously been collected from ground water over a period of 2 years. The oil contained 3.5 percent pentachlorophenol, PCDD, and PCDF homologs ranging from 422 ppb of tetrachlorinated isomers to 83,923 ppb of octachlorinated isomers. The presence of these highly toxic chlorinated dioxins and furans prevented the oil from being transported offsite for incineration. Bringing in and operating a mobile incinerator for onsite destruction of the contaminated oil was rejected because of high costs entailed.

5.2.2 Field Tests

The field equipment used to process the oil consisted of a 2700-gallon reactor mounted on a 45-foot trailer equipped with a boiler, cooling system, laboratory, and control room. The oil and reagent were mixed and heated by using a pump and a high-shear mixer to recirculate the oil and KPEG through a shell and tube heat exchanger. A boiler was used to heat the heat-transfer fluid on the shell side of the heat exchanger, and a series of fin-type air coolers were used to cool the liquid. Figure 1 presents a schematic of the mobile field equipment.

The PCDD- and PCDF-contaminated oil was treated in five batches, each consisting of 1400 to 2000 gallons. Each batch required 600 gallons of KPEG reagent. The mixture was heated to 150°C and allowed to react for 1.5 hours before cooling. The treated oil was pumped out of the reactor and into a holding tank to confirm (by subsequent analysis) that the PCDDs and PCDFs in the oil had been destroyed to a level below detection limits.

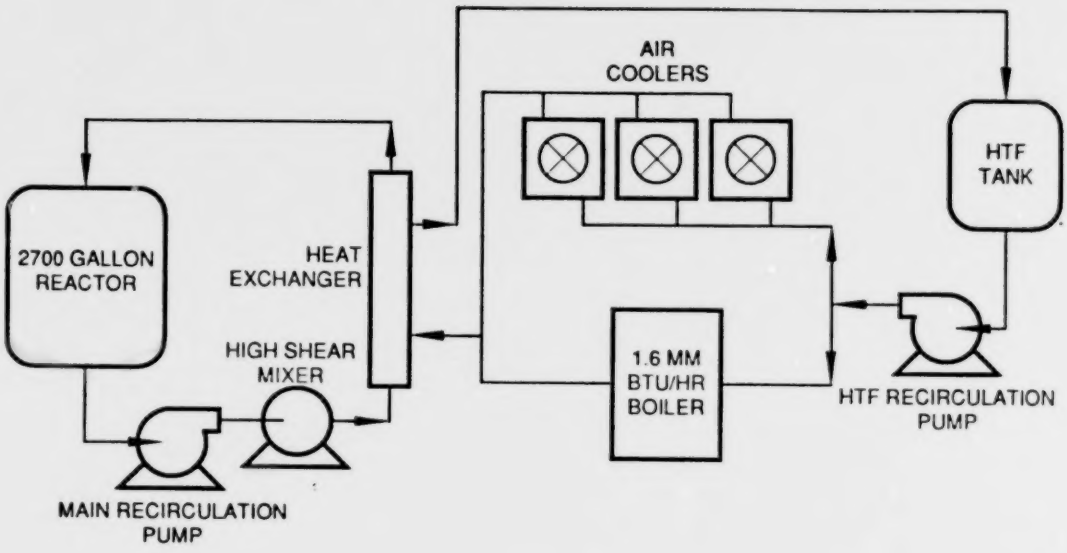


Figure 1. Schematic of mobile field equipment.

5.2.3 Results and Discussion

The data from the sampling and analysis of each tank revealed that all PCDDs and PCDFs were destroyed to less than 1 ppb at a treatment cost of only 10 percent of the projected incineration cost. Toxicity tests performed on the products of the APEG reaction process showed that the reaction products were not harmful to fish or mammals.

5.3 KENT, WASHINGTON: FULL-SCALE TREATMENT

The purpose of this study was to evaluate further the mobile KPEG treatment unit at the Western Processing site in Kent, Washington, which contained 2,3,7,8-TCDD-contaminated waste. The study was conducted at the site in August 1986.

5.3.1 Description of Contaminated Matrix

Stored on site was approximately 8000 gallons of 2,3,7,8-TCDD-contaminated liquid waste. The matrix consisted of oils, solids, water, and pesticides, and was a heterogeneous mixture. Stored for several years in 55-gallon drums, the waste had settled out into three distinct phases: an upper liquid phase, a center semisolid phase, and a lower solid phase.

5.3.2 Field Tests

After the successful demonstration of a mobile KPEG treatment unit at the Butte, Montana, site, the equipment was transported to Kent, Washington, and used to treat the contaminated waste there. The field equipment and the operating parameters of the treatment process were similar to those used for the Butte, Montana, full-scale treatment.

5.3.3 Results and Discussion

The data from the sampling and analysis of treated samples showed that a reaction time of 12 hours was required to reduce the TCDD from 120 ppb to less than 0.3 ppb.

SECTION 6

BENCH-SCALE SOIL TREATABILITY STUDIES

6.1 CLOVERDALE, CALIFORNIA

The purpose of this study was to determine the effectiveness of the KPEG reagent on the PCB-contaminated soil from the MGM Brake site in Cloverdale, California. The study was performed at EPA's Risk Reduction Engineering Laboratory (RREL) in Cincinnati, Ohio (Rogers 1989).

6.1.1 Description of Contaminated Matrix

The soil from the MGM Brake site was a heavy clay loam contaminated with PCBs (Aroclor 1242 and 1248). The soil was also found to contain PCTPs. The concentration of PCB in the soil was approximately 640 ppm. The concentration of PCTP was not determined.

6.1.2 Experimental Procedures

The KPEG reagent used in this study was prepared from PEG-400 and KOH. The bench-scale testing of the KPEG technology was performed on four 20-gram aliquots of contaminated soil.

The experimental setup included a reaction flask outfitted with a stirrer, a distillation head, a condenser, and a receiving flask. An electric heating mantle was used to heat the reaction mixture.

The reagent was usually added to the flask containing the contaminated soil (reagent-to-soil ratio of 1:1 by weight). The stirring and the heating were initiated, and the temperature of the reaction ranged between 125° and 145°C. A time period of 4 hours was permitted for the reaction to occur.

After the predetermined time period had elapsed, the reaction flask was cooled, and 10 to 20 percent hydrochloric acid (HCl) solution was used to neutralize the reaction mixture.

6.1.3 Results and Discussion

The KPEG treatment reduced the concentrations of PCTP in the soil to below the detectable range. The PCB concentrations in the soil were reduced by varying amounts, possibly because of poor mixing.

6.2 GUAM, U.S.A.

The goals of this EPA-sponsored study performed at the RREL in Cincinnati, Ohio, were as follows:

1) To determine the effectiveness of the KPEG reagent on PCB (Aroclor 1260) contamination in Guam soil.

2) To increase the reactivity of the reagent so the treatment time could be reduced.

3) To reduce any residual PCB congeners in the final treated soil to less than 2 ppm.

4) To evaluate whether DMSO and triethylene glycol methyl ether (TMH) could be removed from the reagent formulation without sacrificing PCB destruction or increasing reaction time.

6.2.1 Description of Contaminated Matrix

The Guam soil contained about 20 to 80 percent coral, by weight, and had a pH of approximately 8. The PCB (Aroclor 1260) contamination in the soil was between 200 and 48,000 ppm. The soil had to be screened to a particle size of no more than 0.5 inch before being loaded into the experimental reactors. The Guam soil used during this study had a PCB concentration of about 2200 ppm.

6.2.2 Experimental Procedures

The KPEG reagent used in this study was prepared by reacting PEG-400 and KOH. The bench-scale testing was performed on samples of contaminated soil ranging from 10 to 100 g each.

The experimental setup included a reaction flask outfitted with a stirrer, a distillation head, a condenser, and a receiving flask. An electric heating mantle was used to heat the reaction mixture.

The reagent was added to the flask containing the contaminated soil. The reagent-to-soil ratio was lowered from 1:1 to 0.5:1. The temperature of the reaction ranged between 120° and 180°C, and the reaction time ranged from 3 to 6 hours.

After the predetermined amount of time had elapsed, the reaction flask was allowed to cool for 15 to 45 minutes, depending on the size of the flask. The reaction mixture was then neutralized with 10 to 20 percent HCl to bring the pH to less than 9.

Several bench-scale experiments entailed developing procedures for recovering reagent. The reaction mixture was washed with water to remove the reagent. Between 20 and 50 percent of the reagent was usually recovered. The reagent-recovery step required considerable time and energy.

6.2.3 Results and Discussion

The PCB-contaminated Guam soil was found to be amenable to treatment by the KPEG reagent without the use of DMSO or TMH as cosolvents. The KPEG treatment lowered all PCB congeners to less than 2 ppm. Tetrachlorobiphenyl, the most prevalent and resistant PCB in this soil, also was lowered to less than 2 ppm. The ratio of KOH:PEG was raised from 1:1 to 1.3:1 on a weight basis. This permitted more effective treatment and reduced the resistant tetrachlorobiphenyl congener to less than 2 ppm in 3 hours of reaction time.

6.3 MECHANICSBURG, PENNSYLVANIA

The purpose of this study was to determine the effectiveness of APEG treatment on PCB-contaminated soil from Mechanicsburg, Pennsylvania. The study was performed at EPA's RREL in Cincinnati, Ohio.

6.3.1 Description of Contaminated Matrix

The soil obtained from Mechanicsburg was contaminated with PCBs (Aroclor 1260) and assorted aromatic and aliphatic hydrocarbons. The PCB concentration in the soil ranged from 200 to 900 ppm.

6.3.2 Experimental Procedures

The KPEG and NaPEG reagents used in this study were prepared by reacting PEG-400 and KOH and PEG-400 and NaOH, respectively. The experimental setup and procedure were similar to those used for the Guam soil.

6.3.3 Results and Discussion

The PCB-contaminated soil was found to be amenable to KPEG/NaPEG treatment. The PCB concentrations in the soil were reduced from 200 to 900 ppm to less than 2 ppm per residual PCB congeners.

SECTION 7

DRUM-SCALE TREATMENT

7.1 OMAHA, NEBRASKA

The purpose of this study was to demonstrate the effectiveness of the KPEG process on drummed herbicide wastes containing dioxins. The study was conducted in 1987 at the site in Omaha, Nebraska (Rogers 1989).

7.1.1 Description of Contaminated Matrix

The herbicide waste contained 2,4-D, 2,4,5-T, and 2,3,7,8-TCDD. The concentration of 2,3,7,8-TCDD was 1.3 ppm, the concentration of 2,4-D was 17,800 ppm, and the concentration of 2,4,5-T was 2800 ppm.

7.1.2 Field Tests

The KPEG reagent used in the field tests was prepared by reacting PEG and KOH. The field-scale testing of the KPEG technology was performed on one 20-gallon batch of waste.

The treatment equipment consisted of a 55-gallon drum, a clamp-on heating band, and a stirring motor. The drum containing the KPEG reagent and the contaminated waste was heated to a temperature of about 70° to 85°C for 2 days, during which time it was continually stirred. After 2 days, the heater was turned off and the reaction mixture was allowed to cool to ambient temperature. The treated waste samples were then analyzed to determine the post-treatment concentration of the targeted compounds.

7.1.3 Results and Discussion

Table 4 presents the results of the field tests. The KPEG treatment reduced the concentration of 2,3,7,8-TCDD in the waste to less than the detectable range. The concentrations of both 2,4-D and 2,4,5-T were reduced by 98 percent.

TABLE 4. DRUM-SCALE TREATMENT OF TCDD, 2,4-D AND 2,4,5-T

Contaminants	Concentration in untreated waste, ppm	First treatment	Second treatment	Percent of reduction
TCDD (2,3,7,8-)	1.3	0.086	ND	100.00
2,4-D	17,800	9000	334	98.12
2,4,5-T	2,800	1700	55	98.04

7.3 BENGART & MEMEL, INC., NEW YORK

Galson Research has patented a chemical process that detoxifies hazardous aromatic halides in contaminated soil. The APEG process has proved to be successful for a variety of soils in both laboratory and field studies. The procedure used at the Bengart & Memel site was a small-scale version of the process in which the soil storage drums were used as reaction vessels (Novosad 1987).

The reagent components include a sulfoxide (e.g., sulfolane or DMSO); a glycol or capped glycol [e.g., PEG-400, TMH, and/or methyl carbitol (MEE)]; solid or aqueous KOH; and water. The glycol is reacted with KOH in the presence of DMSO to form an alkoxide. The alkoxide reacts with one of the chlorine atoms on the biphenyl ring to produce an ether and potassium chloride salt. The sulfoxide acts as a cosolvent/catalyst and increases the overall rate of reaction.

7.3.1 Description of Site

Bengart & Memel, Inc., a wholesaler of nonferrous scrap metals, was founded in 1950 in Buffalo, New York. From the early 1950's through 1978, Bengart & Memel received and dismantled PCB transformers and capacitors. During these operations, they inadvertently released PCBs into the soil. In the mid-1970's, soil samples from the property were found to have a PCB concentration of greater than 50 ppm. The New York State Department of Environmental Conservation (NYSDEC) issued a Consent Order for remediation that required the PCB concentration in the soil to be reduced to less than 50 ppm.

Soil sampling and analysis indicated that seven sites on the property had excessive PCB concentrations. These sites ranged in depth from 6 to 24 inches and were defined as being 10 feet in diameter at about the point where the soil core sample was taken. As part of the remedial program, this soil was excavated and placed in one hundred and sixty-six 55-gallon steel drums.

The processing of PCB-contaminated soil at Bengart & Memel took place in two stages: 1) laboratory simulation of PCB destruction and neutralization, and 2) actual treatment operations at the site.

7.3.2 Field Demonstration

The bulk of the decontamination efforts took place in September and October 1986. Fifty-one drums of soil were staged near the work area for treatment. Because of the consent order deadline, the remaining drums (except Drum 20) were not processed, but were shipped to a landfill. Drum 20 could not be disposed of in a landfill because it had a PCB concentration of greater than 500 ppm. A confirmatory gas chromatography (GC) analysis of the soil gave a PCB level of 1300 ppm. Drum 20 was eventually processed during neutralization of the other drums in February 1987.

The six basic steps involved in soil decontamination at Bengart & Memel were as follows:

1) Setting up the vapor system and enclosure.
2) Adding premixed liquid reagent to soil drums.
3) Attaching heaters, insulation, and vent lines to the drums.
4) Allowing the drum contents to heat and react.
5) Cooling and obtaining a sample for analysis.
6) Neutralizing the caustic soil.

The drums were filled with soil to within 2 to 6 inches from the top to allow for the addition of the liquid reagents. An aluminum tube was driven through the dry soil to the bottom of the drum to allow air to escape during liquid addition; otherwise, an air pocket would form and prevent the downward movement of the liquid. The single-phase reagent mixture (2:2:4:9:5 PEG:TMH: DMSO:45 percent KOH:water) was added to the soil drums by weight, typically between 150 and 170 pounds. Because the KOH reacted with aluminum, when the reagent reached the bottom of the drum, foam exiting the tube would indicate that the air pocket had been expelled. The tube was then removed and a bimetal thermometer was inserted into the 3/4-inch bung on the drum cover.

The drums were heated from the bottom to ensure that all of the soil was reacted. Dents and deformities in the drums necessitated the use of a heat-transfer compound to provide adequate contact between the heaters and the metal. It was essential that liquid make contact with the metal on the interior so the heat could be carried away. The soil temperature was monitored 9 to 12 inches below the lid, and the heaters were at the drum's base. Soil temperatures near the heater were higher than those measured near the top. A drum was usually heated for several hours to a maximum temperature readout between 105° and 110°C.

The drums were vented to a central condenser system with a capacity of 16 drums (see Figure 2). During heating, vapors would exit from the drum through an insulated flexible line connecting the 2-inch drum bung to the main header. Part of the header was ice-jacketed so that much of the water vapor was condensed and drained directly into a 55-gallon holding drum. The remaining vapor was drawn through an air-cooled radiator (used as a condenser), which also drained liquid to the 55-gallon holding drum. An ice-jacketed scrubber containing a dilute sodium hypochlorite solution (for odor control) trapped most of the remaining condensables. From the scrubber, the vapor passed through an air trap and a 55-gallon drum that was filled with a mixture of activated carbon and a molecular sieve. A vacuum pump provided negative pressure for the vapor control system.

Treated soil samples were collected by use of a 30-inch auger attached to a hand drill. Four wells were made in each drum--one in the center, one close to the edge, and two spaced between the center and edge in different parts of the drum. Soil was collected by digging as deep as possible with the auger and bringing soil up from the bottom of the hole. Digging out a sample well required working around large rocks in the drum because true core samples were not obtainable. Debris (rocks, metal, wood, etc.) larger than 1 inch in diameter was not included in the sample. The soil from the cores was collected in a plastic bucket and mixed thoroughly with a trowel. Two jars were filled for each sample--one for GRC and one for the EPA. The soil remaining in the bucket was returned to the drum, and the auger, bucket, and

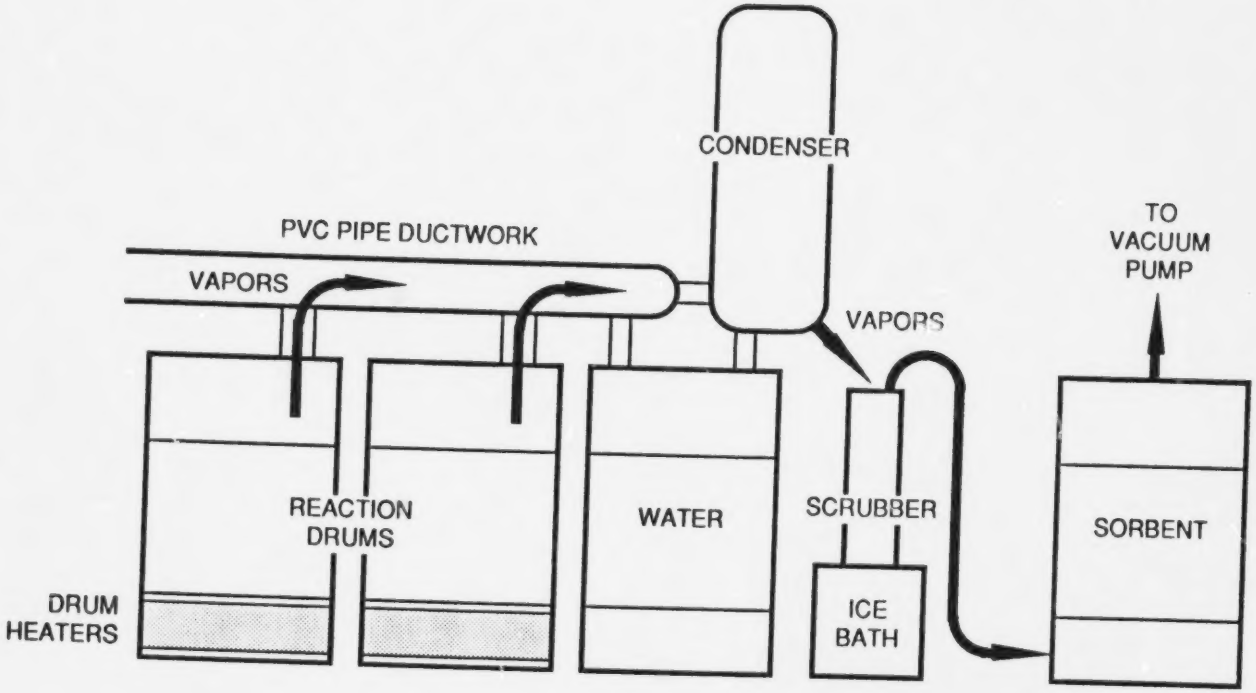


Figure 2. Central condenser system.

trowel were cleaned before the next drum was sampled to avoid cross-contamination.

After the soil had been treated, it had to be neutralized. Mixing was necessary to avoid "hot spots" of concentrated acid or caustic. As a means of providing controlled mixing, it was decided to slowly add the alkaline soil to a drum partially filled with dilute acid. When the liquid became neutral or slightly basic, more acid was added to compensate. Thus, when the acid and KOH reacted, a sufficient mass was present to absorb the heat and to prevent splattering. This procedure required frequent monitoring for pH control.

7.3.3 Results

The analytical results for PCB content during this project can be divided into two groups. Group 1 consists of samples that the EPA analyzed soon after processing and found to contain less than 50 ppm of PCBs. The drums from which the Group 1 samples were taken were neutralized without any further sampling or treatment. The PCB concentrations in the untreated soil and EPA results for the treated soil are summarized in Table 5.

TABLE 5. SAMPLE GROUP 1, ANALYZED ONLY BY EPA

Drum No.	PCB in soil, ppm	
	Untreated	Treated, 10/86
5	119	43
6	119	46
8	62	45
10	128	46
35	910	33
36	91	46
46	123	47
53	64	15
60	61	44
62	65	30
71	69	28
81	74	38
82	67	43
87	62	39
91	91	37
92	138	49
93	91	44
102	69	18
109	87	42
119	64	9
137	62	23
Average	125	36

Group 2 was analyzed by GRC in February 1987. This group includes fresh samples from the drums in which the soil had a PCB concentration of 50 ppm when the EPA analyzed them in October 1986, samples from drums that EPA never analyzed, and one sample with a PCB concentration less than 50 ppm when the EPA analyzed it. All of these drums were sampled in February 1987, after the reagent had been in contact with the soil for 5 months. The low-concentration sample was analyzed by GRC to check the potential reaction progress in drums with PCB concentrations below 50 ppm. Results of GRC's analyses are presented in Table 6.

TABLE 6. SAMPLE GROUP 2, ANALYZED BY EPA AND GRC

Drum No.	PCBs in soil, ppm		
	Untreated	Analyzed by EPA, 10/86	Analyzed by GRC, 2/87
1	138	71	19
4	84	60	20
9	64		8
11	128	90	30
20A	1300		<5
20B	1300		94
37	64	74	12
43	102		7
44	72	51	31
45	195	59	27
54A	78		10
54B	78		49
63	167		16
64	64		13
72	119		12
83	78		18
85	78	56	16
86	84	74	22
101	74		11
111	64	51	22
112	110		33
113	67	78	17
114	102	57	27
120	75	26	<5
121	62		24
122	106	65	22
131	78		17
135	106		28
Misc. A	NA[a]		33
Misc. B	NA		17
Misc. C	NA		9
Misc. D	NA		6
Misc. E	NA		15
Average	179	62	22

[a] NA = Not analyzed.

The reduced concentrations reported in February (compared with the October results) indicate that the reaction continued during the holding period.

The only soil in which the PCB concentration was not reduced to below 50 ppm came from a drum with particularly high concentration (Drum 20, 1300 ppm) that the site owner was not able to landfill. Drums 20 and 54 were processed in February 1987 during the neutralization procedures. The soil from these drums was split and transferred into four drums (20A, 20B, 54A, and 54B) to ensure good reagent permeation and better heat transfer. The PCB level in Drum 20B was reduced by 93 percent, to between 73 and 104 ppm. The PCB levels in Drums 20A, 54A, and 54B were all reduced to less than 50 ppm.

In summary, the APEG processing used at the Bengart & Memel site was successful in reducing PCB levels in 51 of 52 drums to below the 50-ppm control limit set for the site. For those 51 drums, the average PCB levels were reduced 75 percent, from 108 to 27 ppm. The PCB level for the sole remaining drum was reduced by 93 percent, from 1300 to 78 ppm.

SECTION 8

FIELD-SCALE SOIL TREATMENT

8.1 MOREAU, NEW YORK

In June 1987, PEI and Galson Research Corporation (PEI's subcontractor) conducted a pilot-scale field demonstration at Moreau, New York, to evaluate the effectiveness of the KPEG treatment process for the chemical destruction of PCBs. The purpose of this field demonstration at Moreau was to develop the KPEG technology further by scaling up the laboratory-scale process to a small, pilot-scale (40-gallon) reactor. The demonstration was conducted for two reasons: 1) to document that the 40-gallon KPEG reactor is effective in dechlorinating PCBs to acceptable levels (from thousands of parts per million to less than 3 to 4 ppm), and 2) to gather data for use in the design of a larger (2-cubic-yard or 400-gallon) reactor to be used at other locations. Much of the data collected at Moreau was to be used to validate the destruction of PCBs and to validate the analytical methods that would be used for the remaining demonstrations. The test at Moreau was not intended to be a site cleanup; only a small portion of the contaminated soil was treated during the test.

8.1.1 Description of Site

The Moreau site is a former dragstrip located in South Glens Falls, New York, approximately 50 miles north of Albany. The site is in a sparsely populated area with small trees and fields, and the topography is flat. The dragstrip area was oiled periodically. Some of the oil used was transformer oil containing PCBs. The PCB concentrations in the site soil range from nondetectable up to tens of thousands of parts per million. The site is now closed and secured by fencing and locked gates. The nearest residences are about 0.5 mile from the site.

An area of PCB-contaminated soil had previously been mixed by rototilling. The soil collected for the runs came from this area, which was considered a "hot zone." The trailer containing the reactor and a small laboratory was located in a clean area. The laboratory was equipped with a GC to analyze for PCBs during the testing.

8.1.2 Description of Process Equipment

Figure 3 shows details of the pipe reactor used during the tests at Moreau. The reactor, which was constructed from a 40-inch length of 16-inch

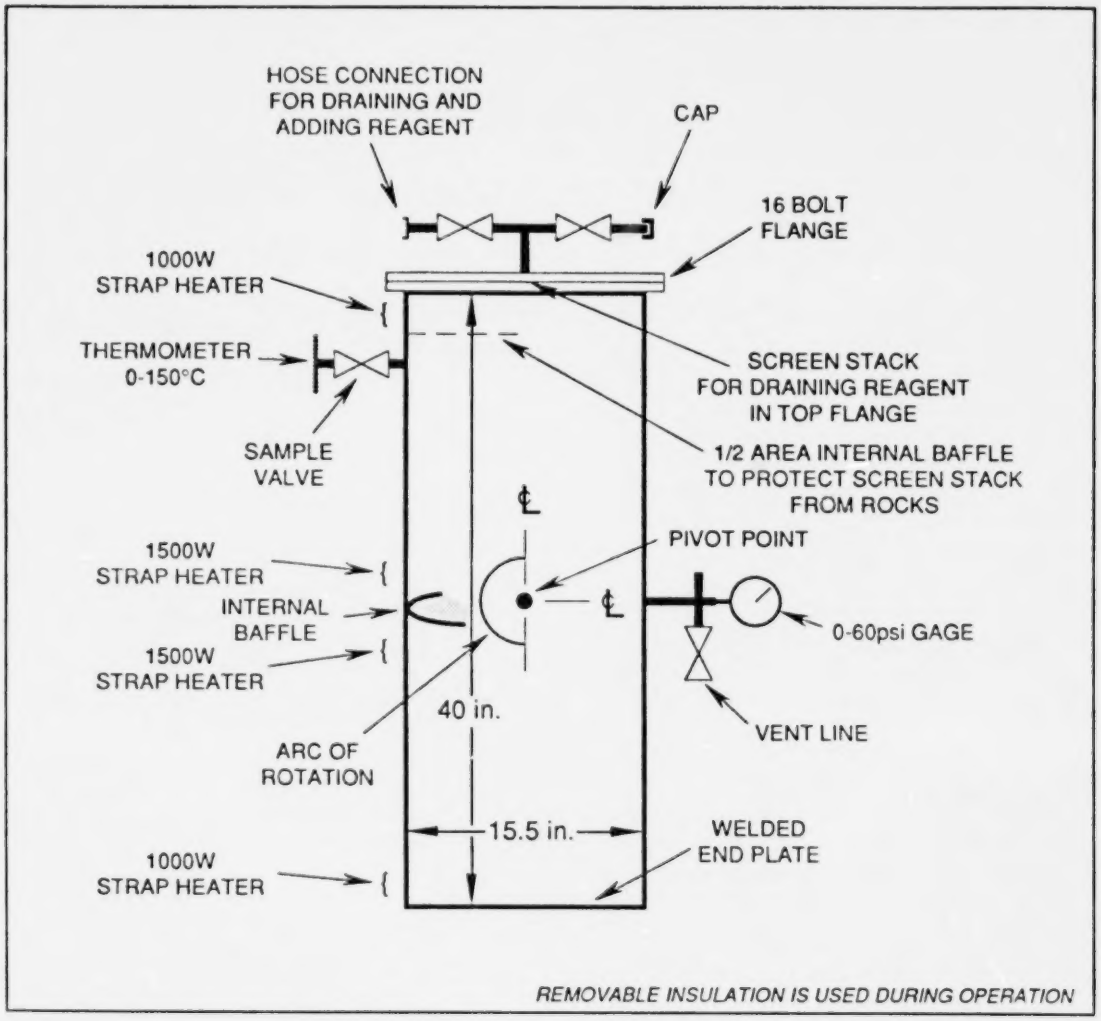


Figure 3. Reactor detail.

steel pipe, was mounted on a stand that allowed it to rotate about its centerline. The reactor rotated through a 180-degree arc every 10 seconds. Thus, mixing was very gentle inside the pipe. A baffle located midway down the side of the pipe redirected the flow of slurry along the wall of the pipe and enhanced mixing. Another baffle was located near the flanged end of the pipe and covered about half the pipe area. The purpose of this baffle was to prevent rocks and other heavy objects from falling directly onto the flange and damaging the screen that was an integral part of the flange.

The pipe had an end plate welded on one end and a 16-bolt flange on the other end. The flanged end was tapped and piped to a tee. Each arm of the tee lead to a shutoff valve. One shutoff valve was capped, and the other went to a hose connection. This hose connection was used for adding liquids to and draining them from the reactors. A screen stack consisting of a 16-mesh screen followed by 20-mesh screen was located on the top flange. This screen stack was used to strain the reagent from the soil after the reaction.

A 0° to 150°C thermometer was located in the side of the pipe, just below the baffle. This thermometer was inserted through a ball valve that was used to sample the reactor contents. To take a sample, the reactor was first placed in an upright position so that its contents would be at the bottom. The thermometer was then unscrewed, and the reactor was tipped over to allow slurry to flow to the valve. Samples were taken in a porcelain-lined pot. The valve was shut as soon as the sample was collected. The reactor was then rotated back to an upright position, the valve reopened, and the thermometer was reinserted. A second thermometer was located on the opposite side of the reactor, but this thermometer was not used during the test. The thermometer used during the test was calibrated with a laboratory thermometer by placing both thermometers in a beaker of water on a hot plate and heating the water to the boiling point. The thermometers were within 5°C of each other up to the boiling point. At the boiling point, the laboratory thermometer read 101.8°C and the reactor thermometer read 99.8°C.

A tap near the center of the reactor pipe was connected to a four-way connector. One of the four-way connector openings was connected to wires that went to a temperature recorder; however, this device was inoperable during the test. The second opening was connected to a 0- to 60-psig pressure gauge. The third opening was connected to a valve that was connected to a flexible hose that served as the vent line during the tests.

Heat was supplied to the reactor by four electric heating straps, each of which was wired through a rheostat so the voltage could be controlled. One 1000-watt heating strap was wrapped around the top of the reactor, and a second 1000-watt strap was wrapped around the bottom of the reactor. These straps were about 10 inches wide. Two 3-inch-wide, 1500-watt straps were wrapped around the center portion of the reactor.

During reactor operation, the temperature and pressure were recorded every 15 minutes. In addition, the reactor was stopped in the vertical position every 15 minutes and the reactor was pounded with a rubber mallet to

dislodge any contents that might have stuck to the wall. The reactor motion and direction were controlled by a hand-held switch; thus, during the entire time the reactor was operating, a person holding the switch had to reverse the reactor's direction manually at the end of each 180-degree turn.

Figure 4 shows the arrangement of the reactor vent system. The reactor initially vented through an air condenser mounted on the wall of the trailer, which drained into a 55-gallon drum. Because the fan blew across the air condenser and then outside, it also provided some ventilation for the trailer.

Condensate collection drum No. 1 was, in turn, vented to a copper coil in a container filled with ice water. This condenser then drained into condensate drum No. 2, which was vented to a Nixtox drum that vented to the atmosphere. The Nixtox drum contained activated carbon in molecular sieves to ensure that any remaining volatilized organics that may have passed through the initial condensing system would be trapped.

8.1.3 Process Operation and Operating Conditions

For initiation of the process operation, the soil and reagents were weighed and added into the reactor. The mixture was agitated and the reactor heating elements were turned on. The temperature of the reactor mixture was recorded every 15 minutes and monitored to ensure that it did not exceed 155°C. After reaching a temperature of 150°C, the mixture was held between 145° and 155°C and agitated until the concentration of PCB in the soil reached an acceptable level. At the end of the reaction, the contents of the reactor were sampled, emptied into a drum, and weighed. Gases from the reactor were vented through the ice-cooled air condensers and then through the Nixtox drum.

A series of four tests were run at Moreau. At the start of the testing, four clean reactor pipes were loaded with the soil and then run one at a time. For the first three runs, DMSO, TMH, and PEG-400 were premixed in a 55-gallon drum by adding 100 pounds of DMSO, 50.5 pounds of TMH, and 50 pounds of PEG-400. A drum pump was then used to recirculate this material for about 5 minutes to mix the reagents. The reagents were then pumped into the pipe and mixed with the 45 percent KOH. In the fourth run, sulfolane was used instead of DMSO. For this run, the TMH and PEG-400 were added individually to the reactor. Table 7 shows the materials charged to the reactor during each of the four runs.

TABLE 7. MATERIALS CHARGED TO THE REACTOR
(pounds)

Run No.	Soil	Sulfolane	DMSO	TMH	PEG-400	45% KOH	Total liquid
1	33.5	0.0	11.0	5.5	5.5	11.0	32.9
2	32.5	0.0	10.0	5.0	5.0	10.0	30.0
3	34.0	0.0	12.0	6.0	6.0	12.0	35.9
4	39.0	15.0	0.0	7.5	7.5	13.0	43.0

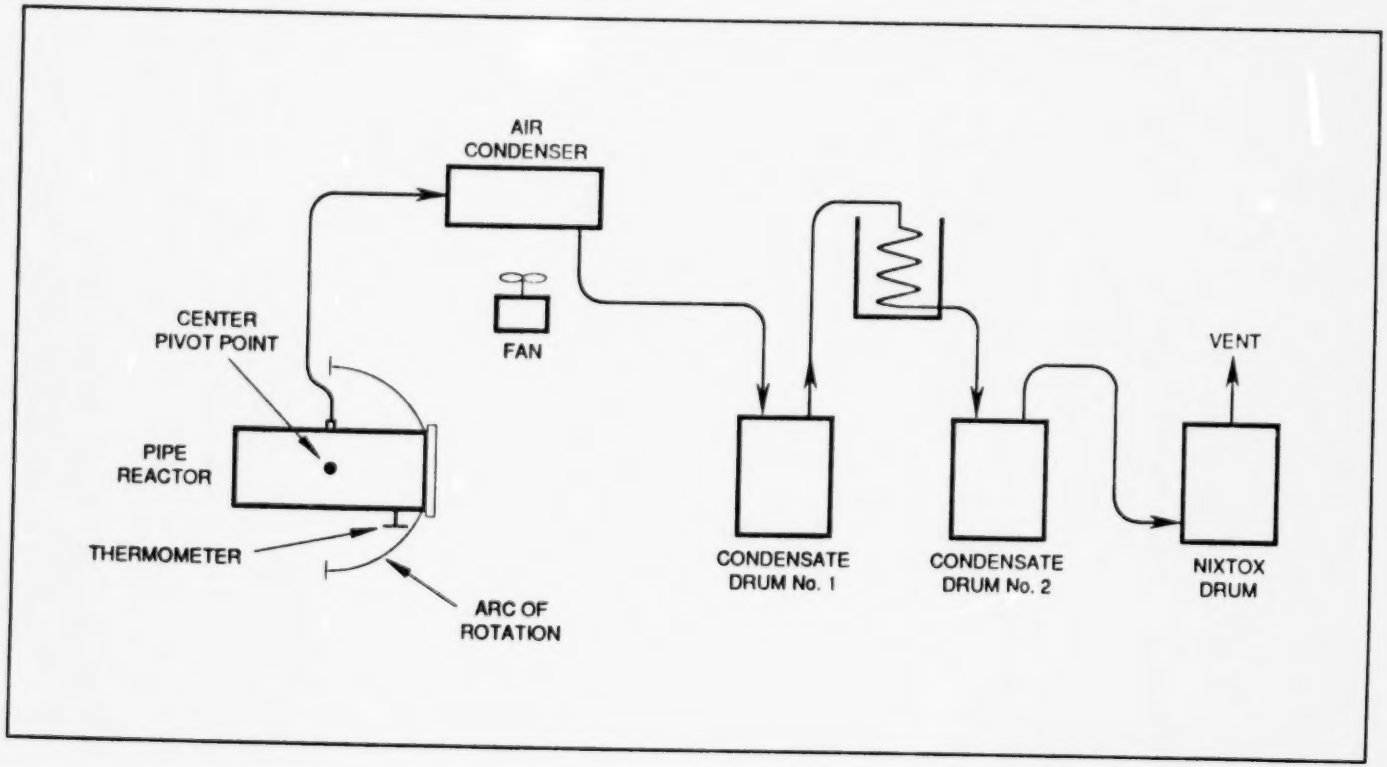


Figure 4. Equipment arrangement for the Moreau Test.

Table 8 presents a breakdown of the contents of the reactor. The moisture content of soil samples ranged from 14 to 18 percent because heavy rains occurred in the area the weekend before the tests began. The water content shown in the table comes from the 45 percent KOH that was added as well as from the moisture already in the soil.

TABLE 8. DETAILED REACTOR CONTENTS

	Run 1	Run 2	Run 3	Run 4
Soil, % water	14.51	14.21	14.53	18.34
Dry soil, lb	28.64	27.88	29.06	31.85
Dry KOH, lb	7.15	6.50	7.80	8.45
Water, lb	12.01	11.12	12.74	15.60
Organics, lb	22.0	20.00	24.00	30.00
Soil/organics	1.30	1.39	1.21	1.06

Based on the total amount of liquid added, as shown in Table 7 (neglecting the soil moisture) and the total amount of liquid drained at the end of the cycle, the reagent recovery averaged 61 percent and ranged from 47 to 68 percent. This unexpectedly high level of reagent recovery was possible because the soil formed into a porous gel-like material during the reaction, from which the reagent drained freely. Some grit passed through the screens during the draining and quickly settled at the bottom of the bucket; however, the drained material was low in total suspended solids (TSS) (from 1908 to 1688 ppm). Table 9 presents the percentage reagent recovery and the reagent TSS.

TABLE 9. REAGENT RECOVERED

		Pounds of water				
Run No.	Initial	Boiled off	Added back	Reagent drained, lb	Recovery, %	Reagent TSS, ppm
1	12.01	10	6.5	15.5	47	1216
2	11.12	6.5	6.5	18.5	62	1544
3	12.74	6.5	8.5	24.5	68	1092
4	15.6	7	8.5	29.0	67	1688

The temperature and pressure of the reactor were recorded every 15 minutes during each of the four runs. The operating conditions, including the temperature and pressure readings, are shown in Tables 10 through 13.

The reactor was continuously vented for the first two runs. It was also rotated through a 180-degree arc during each cycle. For Runs 3 and 4, a nonreacting atmosphere was maintained in the reactor by running nitrogen through

TABLE 10. RUN 1--OPERATING CONDITIONS

Time	Temperature, °C	Pressure, psig	Comments
0415		0	Reactor heat turned on.
0430	44	0	
0445	64	0	
0500	85	0	
0515	100	0	
0530	115	0	
0545	125	0	
0600	129	0	
0615	131	0	
0630	134	0	
0645	137	0	
0700	141	0	
0715	144	0	
0745	152	0	Two middle 1500-watt heaters off.
0800	154	0	
0815	156	0	Insulation removed from top of reactor.
0830	158	0	Insulation removed from bottom of reactor.
0845	157	0	
0900	157	0	
0915	160	0	
0930	156	0	
0945	154	0	
1000	152	0	
1015	148	0	1000-watt heater plugged in.
1030	147	0	
1045	152	0	1000-watt heater unplugged.
1100	151	0	
1115	147	0	1000-watt heater plugged in.
1130	149	0	
1145	152	0	
1200	154	0	
1215	157	0	
1230	153	0	
1245			Sample taken.
1300	148	0	
1315	147	0	
1330	150	0	
1345	153	0	
1400	150	0	
1415	146	0	1000-watt heater plugged in.
1430	148	0	
1445	151	0	1000-watt heater unplugged.
1500	148	0	
1515	146	0	
1540		0	6.5 pounds of well water added to reactor.
1545	115	2	15.5 pounds of liquid drained from reactor.

TABLE 11. RUN 2--OPERATING CONDITIONS

Time	Temperature, °C	Pressure, psi	Comments
0837	20	0	Reactor heat turned on.
0850	60	0	
0915	80	0	
0930	100	0	
0945	112	0	
1000	126	0	
1015	131	0	
1030	135	0	
1045	138	0	
1100	142	0	
1115	148	0	Removed bottom insulation.
1130	150	0	Removed top 3 in. of insulation.
1145	147	0	
1200	142	0	Two 1000-watt heaters turned down 1/4 turn.
1215	146	0	Sample taken.
1230	145	0	
1245	145	0	
1300	145	0	
1315	145	0	
1330	146	0	
1345	145	0	
1400	144	0	Top 3 in. of insulation replaced.
1415	150	0	
1430			Sample taken.
1445			
1550			Removed insulation, shut down reactor.

TABLE 12. RUN 3--OPERATING CONDITIONS

Time	Temperature, °C	Pressure, psi	Comments
0730	20	0	Reactor heat turned on.
0745	41	0	
0800	60	0	
0815	76	0	Added 1 psi from nitrogen tank.
0830	96	1.5	
0845	109	2.5	
0900	119	3.5	
0915	129	5	
0930	138	10	
0945	148	16	
1000	153	21	
1015	155	22.5	
1030	153	23	
1045			Sample taken.
1100	134	20.5	
1115	141	24	
1130	150	29	
1145	158	28	
1200	150	25	
1215	148	24	
1230	160	23	Top heater unplugged.
1245	160	23	
1300			
1315			Sample taken.
1330	134	17	
1345	133	16.5	
1400	137	17.5	
1415	138	18	Bottom middle heater turned on.
1430	145	19	
1445	142	20	
1500	145	20	
1515	143	20	
1530	143	20	
1545	144	20	

TABLE 13. RUN 4--OPERATING CONDITIONS

Time	Temperature, °C	Pressure, psig	Comments
0515	26	15.0	Reactor heat turned on.
0530	49	19.5	Reactor rotated 90°.
0545	69	19.5	Bled reactor to 15 psig after each reading.
0600	84	19.0	
0615	98	19.5	
0630	110	20.0	
0645	121	20.5	
0700	132	22.5	
0715	141	23.0	
0730	149	28.5	
0745	146	15.0	Reactor rotated 180°.
0800	135	18.0	2500-watt heater turned off.
0815	142	23.0	
0830	148	25.0	
0845	136	18.0	
0900	145	23.0	Bled reactor to 20 psig after each reading.
0915	150	25.5	
0930	151	22.0	Turned off 1500- and 1000-watt heaters.
0945	148	20.0	
1000	146	19.5	Turned on 1000-watt heater.
1015	149	22.0	
1030	152	23.0	
1045	147	20.0	
1100	152	22.0	Reactor stopped in level position.
1115	154		1500- and 1000-watt heaters off.
1130	160	28.0	
1245	153	26.0	Started rocking reactor again.
1300	153	23.0	
1315	153	22.0	
1400	148	20.0	
1410	145	19.5	
1425			Last sample taken.

the line that was normally used to drain the reactor. The valve in the vent line was then closed and periodically cracked to control the pressure. The temperature was controlled by turning the electric heaters on and off and by removing portions of the insulation. Thermometer readings above 150°C represented extrapolations, as the thermometer only read to 150°C.

During each run, the reactor was sampled when a temperature of 150°C was reached and periodically thereafter until a sample showed a low PCB concentration. At that point, the reactor was shut down.

During the third and part of the fourth reaction runs, the reactor was rotated through a 90-degree arc. At the end of the third reaction run, the reactor was stopped and the end of the reactor was pounded with a rubber mallet. When the reactor was struck, material could be heard falling from the wall to the bottom of the reactor. This indicates that rotating the reactor only 90 degrees allows material to build up on the wall.

Table 14 shows the initial and final weights after each reaction of the two condensate collection drums and the Nixtox drum. No material was collected in the second condensate drum or the Nixtox drum. Apparently, all the condensate was condensed in the air cooler and came out in the first drum. Whereas the Nixtox drum did gain about 3 pounds during the first run, the absence of a positive weight change in the next three runs indicates that this was probably a measurement error.

TABLE 14. INITIAL AND FINAL WEIGHTS
(pounds)

Run No.	Condensate Drum 1		Condensate Drum 2		Nixtox drum	
	Initial	Final	Initial	Final	Initial	Final
1	50.0	60.0	50.5	51.0	286.5	289.5
2	51.0	57.5	51.0	51.0	289.5	287.0
3	51.0	57.5	51.0	51.0	287.0	287.0
4	52.0	59.0	51.0	51.0	287.0	286.5

8.1.4 Results

The PCB analyses for the pilot-scale demonstration at Moreau were performed on site. Table 15 presents the results of these analyses, which were performed on the samples immediately after they were taken from the reactor. Both soil and reagent were analyzed. The percentage reduction in PCB concentration in the soil ranged from 93.9 to 99.8; average reduction was 98.3 percent. In Run 1, the sample obtained at 4 hours showed a PCB level of 0.7 ppm, whereas the 8-hour sample showed a PCB level of 8.08 ppm. This increase in concentration may have been due to an analytical error. The percentage

PCB reduction in the remaining three runs (Runs 2 through 4) was greater than 99. The PCB concentrations in the reagent during Runs 1 through 4 were 0.16, 74.8, 72.4, and 4.25 ppm, respectively.

TABLE 15. PCB CONCENTRATIONS MEASURED AT THE SITE
(ppm)

	Run 1		Run 2		Run 3		Run 4	
Hour	Soil	Reagent	Soil	Reagent	Soil	Reagent	Soil	Reagent
0	133		779		7013		206	
3							20	
3.5							19.7	157
4	0.7	0.8	50.6	74.8	228			
4.5								
5								
5.5							6.6	
6					23.5	138		
7			1.62					
7.5								
8	8.08	0.16						
8.5								
9					12.4	72.4	1.09	4.25
Conden-sate		1.46					26.05	

The results of this pilot-scale demonstration show that the KPEG process can significantly reduce the PCB concentration in the soil.

8.2 GUAM, U.S.A.

Subsequent to the successful application of the pilot-scale KPEG process in Moreau, New York, plans were finalized for further scale-up. Under EPA Contract No. 68-03-3413, the U.S. EPA/RREL authorized PEI to undertake the design, assembly, and evaluation of a KPEG treatment system capable of treating PCB- and PCDD-contaminated soil in batches of 1.1 to 1.5 m^3 (1.5 to 2 yd^3) each. Upon completion of the design and final selection of equipment, PEI engineers and technicians assembled the system in a warehouse in Cincinnati, Ohio. The assembled system was then disassembled, marked with appropriate field erection notes, and crated for transport via tractor-trailer to Port Hueneme, California, where it was loaded onto a U.S. Naval cargo ship and shipped to the Island of Guam, U.S.A. The crew of PEI engineers and technicians then traveled to Guam, where they reassembled the KPEG field-scale treatment system on the U.S. Navy Public Works Center (USN-PWC) site and demonstrated its effectiveness.

8.2.1 Description of Site

In a joint venture between the U.S. EPA/RREL and Naval Civil Engineering Laboratory (NCEL), U.S. Navy Interagency Agreement IAG RW 17933209, a U.S. Navy site was selected for the field-scale demonstration of the KPEG chemical dechlorination system. The U.S. Navy Public Works Center (USN PWC) on the Island of Guam, U.S.A., was selected when analytical results of the collected soil samples indicated average PCB concentrations of 2500 ppm with "hot-spots" as high as 45,860 ppm (4.58 percent). Soil contamination, which occurred mainly in a nearby storm drainage ditch, resulted from leaks from a building where transformers were reworked. This building had been used since as early as World War II. Leaks of waste PCB oil stored outside the building were carried by surface runoff onto the ground and into the drainage ditch.

Figure 5 indicates the sampling dates, locations, depths, and the PCB concentrations found in samples collected at or near the site. The transformer rework building alluded to above is shown as Building 3009. As Figure 5 shows, these soils contain sufficient PCB contamination to warrant concern.

8.2.2 Preparation of the Soil for Treatment

8.2.2.1 Soil Excavation--

Using an excavator and dressed in Level C protective clothing, USN PWC personnel excavated contaminated soil from the ditch before the PEI crew arrived. Navy personnel built a 30.5-m by 30.5-m (100-ft by 100-ft) concrete pad for installation of the field-scale KPEG treatment system. They also erected a 12.2-m by 18.3-m (40-ft by 60-ft) metal building on the concrete pad and lined it with a heavy rubber liner for temporary storage of the excavated contaminated soil. A front-end loader transferred the excavated soil to the metal building. Figure 6 shows the location of the concrete pad and metal building.

8.2.2.2 Soil Screening--

The Navy purchased a diesel-operated mechanical screening device and brought it on the site. The interchangeable screens were adjusted so that particles 1/2 inch and larger would be rejected. Soil and particles smaller than 1/2 inch passed through the screens and were collected separately.

Sizing the soil and particulates to 1/2 inch was not an arbitrary decision. The maximum size of 1/2 inch was established by the mixer manufacturer. After an evaluation of the mixing and heating efficiencies of various mixers and manufacturers, the unit with the greatest combined mixing and heat transfer efficiency was selected. The selected mixer had a shaft along the center axis of the mixing cylinder. Arms protruding radially from this shaft supported plows that were used to mix and fluidize the mixer contents. According to the manufacturer of the selected mixer, the maximum tolerance permitted between the plow and cylinder wall (without substantially sacrificing mixing and heat-transfer efficiency) was 5/8 inch. To avoid the jamming of particulates between the plow and cylinder wall, the mixer manufacturer established a maximum particle size of 1/2 inch.

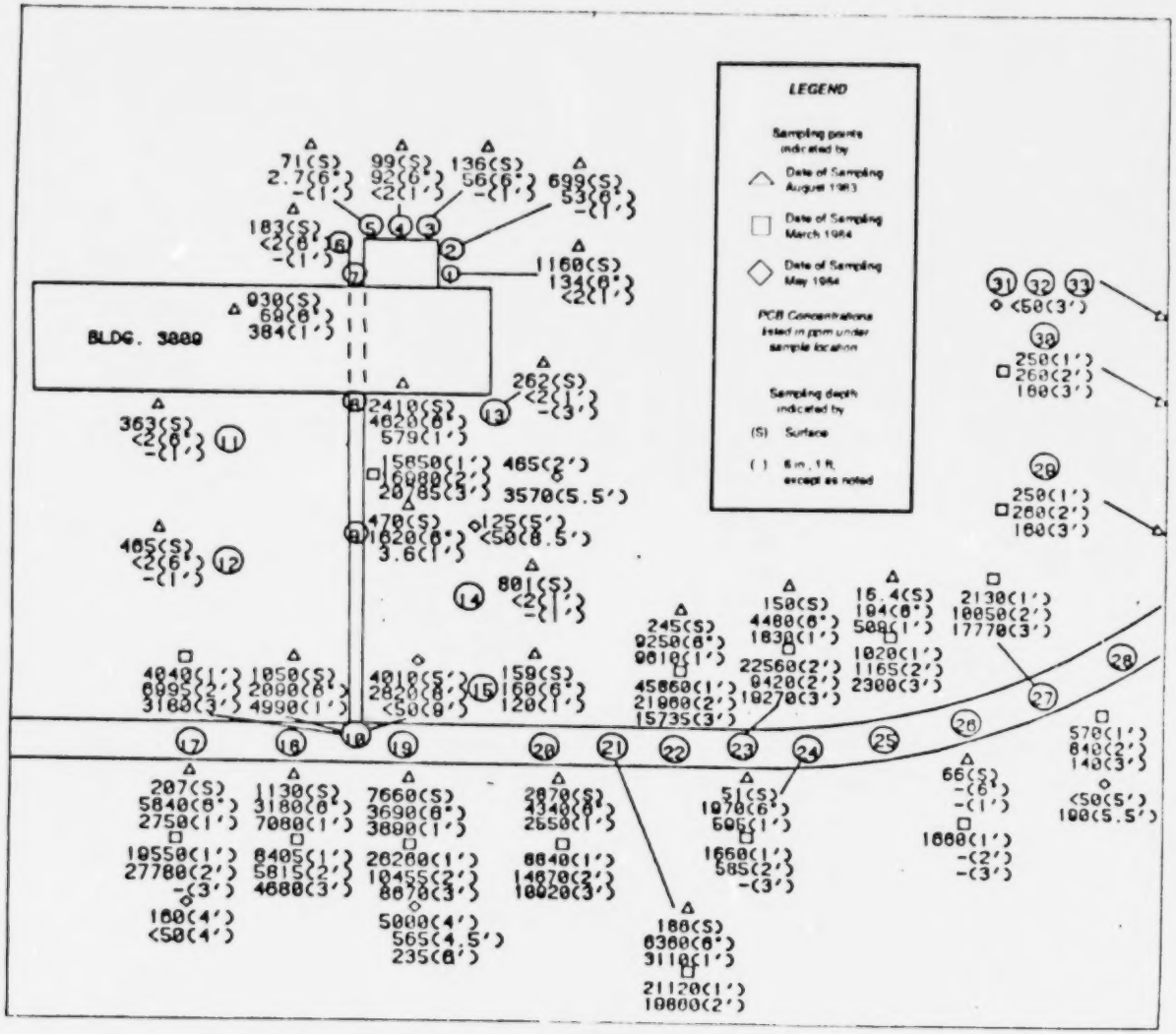

LEGEND
Sampling points indicated by
Date of Sampling August 1983
Date of Sampling March 1984
Date of Sampling May 1984
PCB Concentrations listed in ppm under sample location
Sampling depth indicated by
(S) Surface
( ) 6 in. 1 ft. except as noted
BLDG. 3000

Figure 5. PCB concentration distribution (ppm), U.S. Naval Station, Public Works Center, Guam.

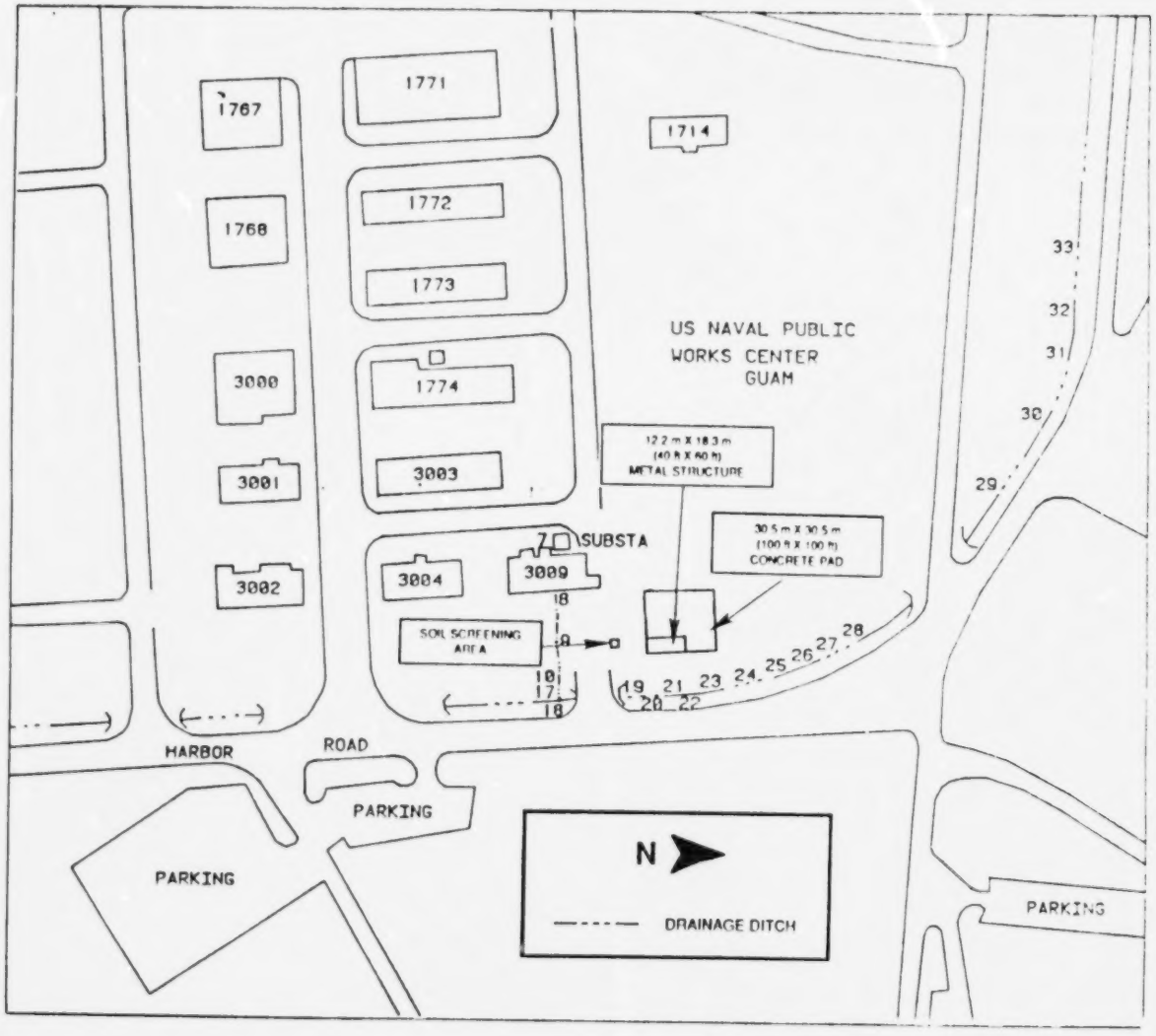


Figure 6. Storage of PCB-contaminated soil and location of field-scale KPEG demonstration.

The procedures used to screen the excavated soil deviated slightly from the screen manufacturer's written procedures because the screening operation was performed outside and dust control was a primary concern. A front end loader was used to transport a load of soil from the metal building and place it on the top screen of the screening mechanism. The entire screen was then covered with plastic to reduce dust emissions. When turned on, the screens (which were mounted on springs) would vibrate, and particles small enough to pass through the screens would be collected. Particles that could not pass through the screens would vibrate off of the slanted screen and be collected in an "oversize-material" pile. The entire 15.3 m^3 (20 yd^3) of soil was screened in this manner.

8.2.2.3 Storage of Screened Soil--

The screened soil was returned to the metal building, where it was stockpiled separately. Approximately 11.5 m^3 (15 yd^3) of the 15.3 m^3 (20 yd^3) of soil passed through the 1/2-inch screen and was ready for KPEG treatment. The remaining 3.8 m^3 (5 yd^3) was classified as oversize and was stockpiled separately for subsequent special processing.

8.2.3 Laboratory Studies

Results of the Moreau, New York, pilot-scale KPEG demonstration indicated that the treatment technology was viable for the dechlorination of PCBs and possibly other haloorganic compounds and that scale-up was possible. Although information collected during the Moreau demonstration was not comprehensive enough to provide full support for the detail needed for the field-scale scale-up, it was sufficient for system design work to begin while laboratory work was being performed on site-specific soil from Guam.

Laboratory studies with samples of contaminated soil from Guam were performed to determine the potential for KPEG treatment of the soil, to determine the reagent formulation and other operating parameters, and to determine whether DMSO and TMH could be removed from the reagent. Laboratory studies were performed in Cincinnati, Ohio, by U.S.EPA-RREL and PEI personnel concurrently with PEI's initial system design (refer to Subsection 7.2). Laboratory results and conditions were factored into PEI's design of the field-scale system.

Removal of DMSO from the formulation was appropriate from a health and safety standpoint. The excellent solvent characteristics of DMSO, coupled with the known rapid rate of skin penetration posed serious concerns for workers in the presence of compounds such as PCBs and PCDDs. In addition, while using noncontaminated soil during an evaluation of a prototype mixer in a manufacturer's facility, a fire occurred when air accidently entered the mixer through a leaky seal and contacted with the reactor contents (DMSO, TMH, PEG-400, and KOH). DMSO or TMH vapors were suspected of having been ignited either spontaneously or in conjunction with static electricity. In any case, laboratory studies led to the finding that DMSO and TMH were not needed to accomplish degradation of the PCBs present in Guam soil.

8.2.4 Field-Scale KPEG System Design

On the basis of the results obtained from the laboratory studies and from the pilot-scale demonstration at the Moreau, New York, site, PEI engineers designed the KPEG treatment system for the demonstration at the Guam site. Figure 7 is a simplified mechanical flow diagram of the KPEG system. As shown, the mixer was the primary component of the system where the chemical dechlorination process occurred, and it was supported by ancillary equipment to make the system functional. An extensive pipe network was required to interconnect the pieces of ancillary equipment to each other and to the mixer. As a means of reducing the complexity of the piping network, a centralized pipe rack was designed for all interconnecting piping. A layout of the Guam site in Figure 8 shows the locations of all ancillary equipment. The majority of the auxiliary system was located outside the exclusion zone so it could be easily accessed without requiring Level C protection. Only equipment contacting the soil in its contaminated state and the equipment that had to be immediately adjacent to the mixer were in the exclusion zone. Figures 9 and 10 present a detailed mechanical flow diagram of the system and a detailed layout of the site plan, respectively.

8.2.5 Description of Process Equipment

The principal components of the KPEG treatment system used in the Guam field test are described in the following subsections.

8.2.5.1 Mixer (KPEG Reactor)--

The selected mixer was designed with a total capacity of 793 gallons (106 ft^3) and a working capacity of 490 gallons (65 ft^3). The mixer was equipped with a 75-hp motor and a gear box capable of providing mixer shaft speeds of 30 and 60 rpm. All parts that were likely to be wetted were constructed of 316 stainless steel to prevent corrosion. The mixer had an 8-inch-diameter shaft that ran the length of the mixing cylinder and was supported at each end by the positive-flow nitrogen-purged seals. Extending radially from the shaft were arms with V-shaped plows that maintained a 5/8-inch tolerance from the wall. The manufacturer recommended that a maximum tolerance of 5/8 inch be maintained between the plow and wall to prevent the creation of a dead zone where caking could occur, which would substantially reduce mixing and heating efficiencies. This 5/8-inch tolerance also established the maximum allowable particulate size of 1/2 inch to assure that no particulate jamming occurred between the plow and wall.

Figure 11 presents a diagram of the selected mixer and the design features. Three 2-inch and one 1-inch flanged liquid charge ports were located along the top of the mixer for the addition of PEG-400 and sulfuric acid. One 1-inch charge port was provided at each headwall of the mixer for the addition of water. A 12-inch Teflon-coated rupture disc was provided at the top of the mixer as a precautionary measure against overpressurization of the mixer. A 2-inch vent that led to the condensate collection system was also provided.

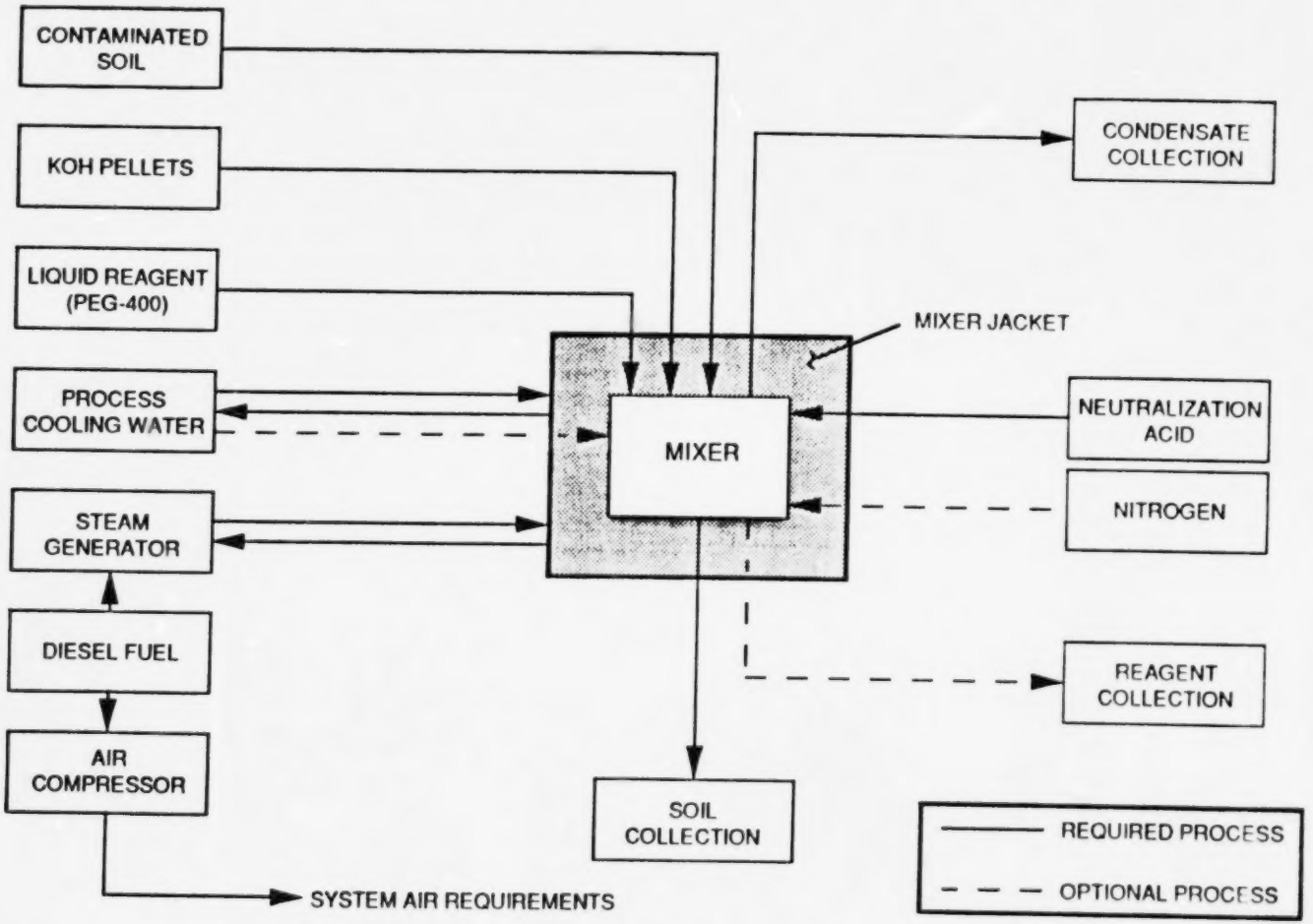


Figure 7. Simplified mechanical flow diagram of KPEG field-scale treatment system.

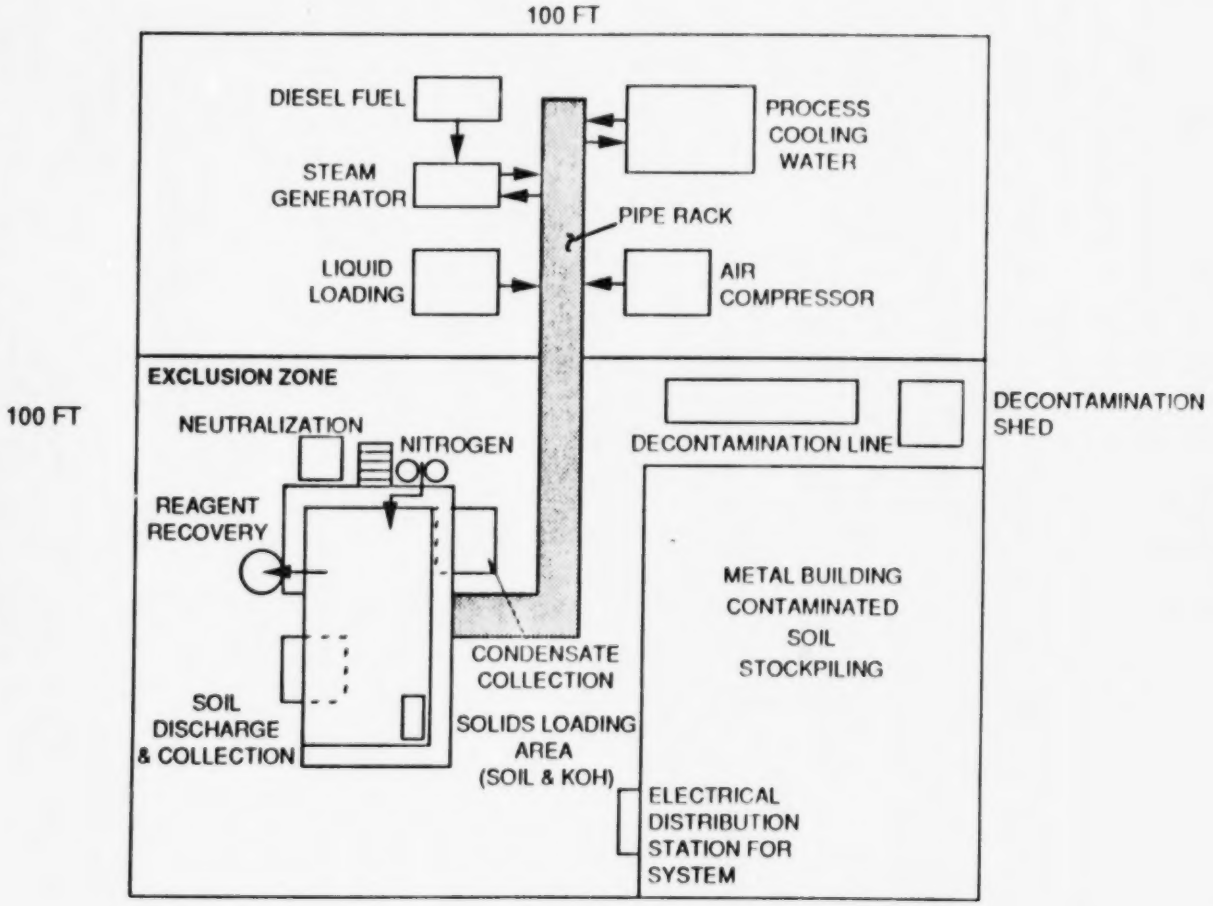


Figure 8. Layout of the Guam site showing locations of ancillary equipment.

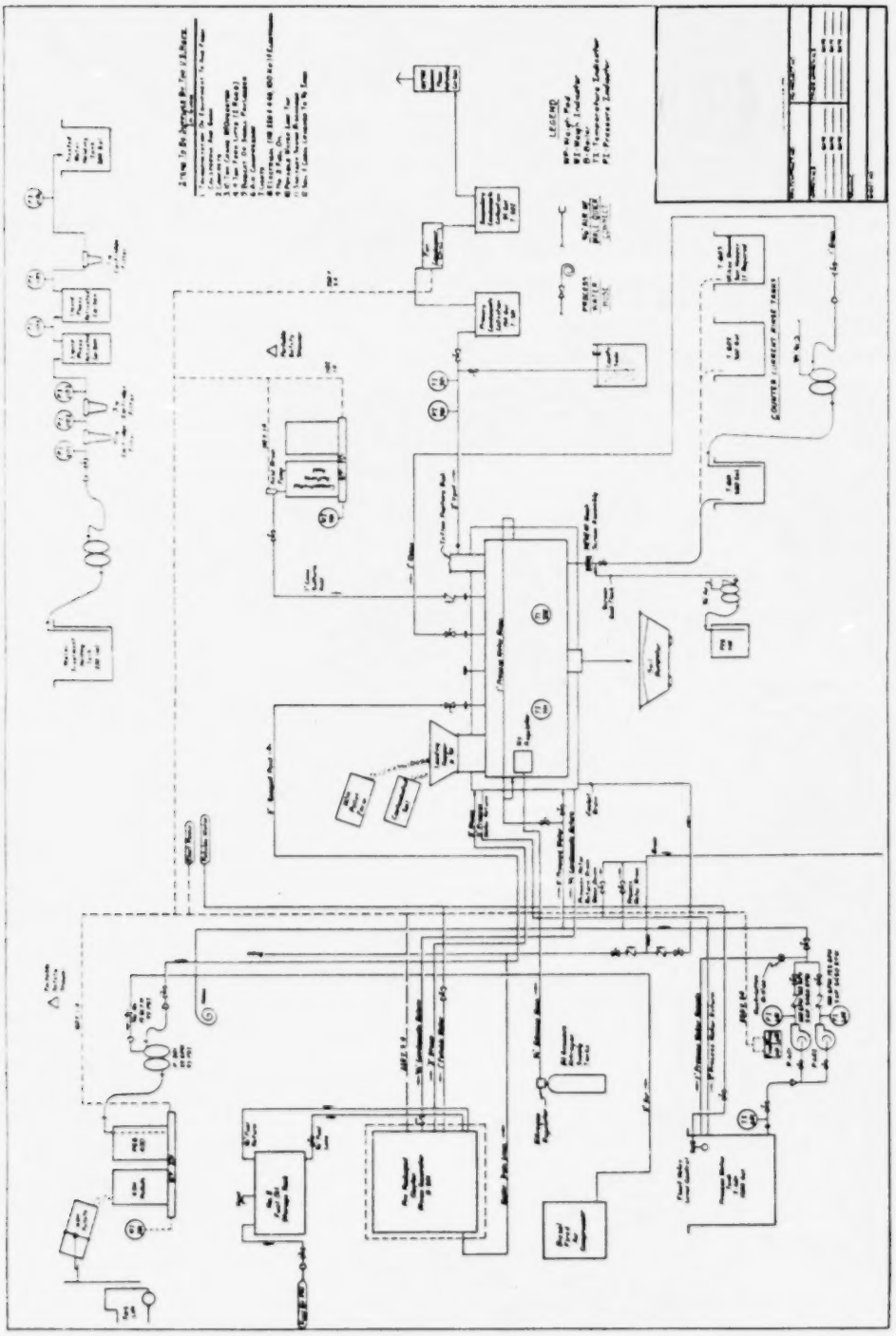


Figure 9. Detailed mechanical flow diagram of KPEG field-scale treatment system.

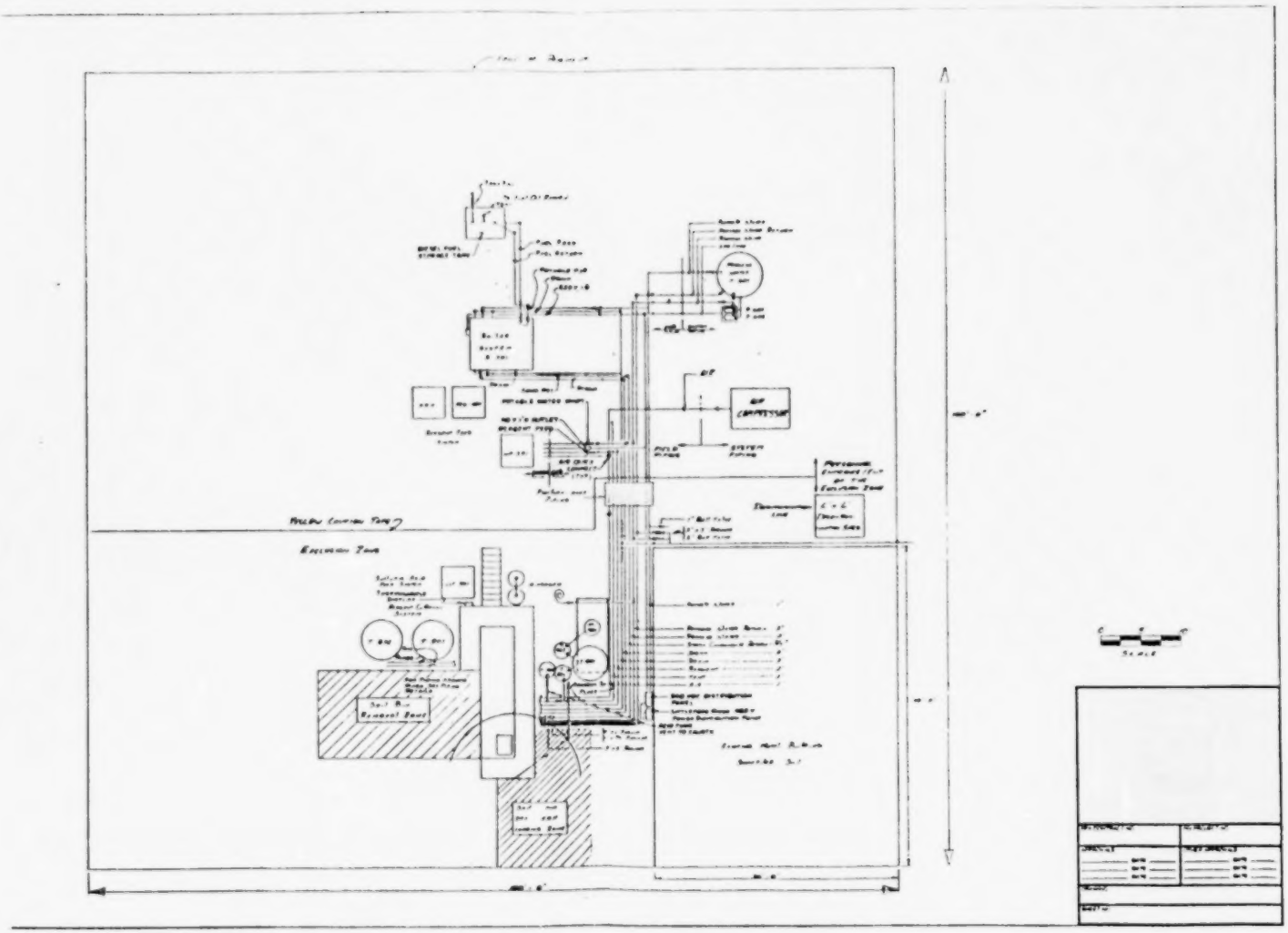


Figure 10. Detailed site plan for KPEG field-scale treatment system.

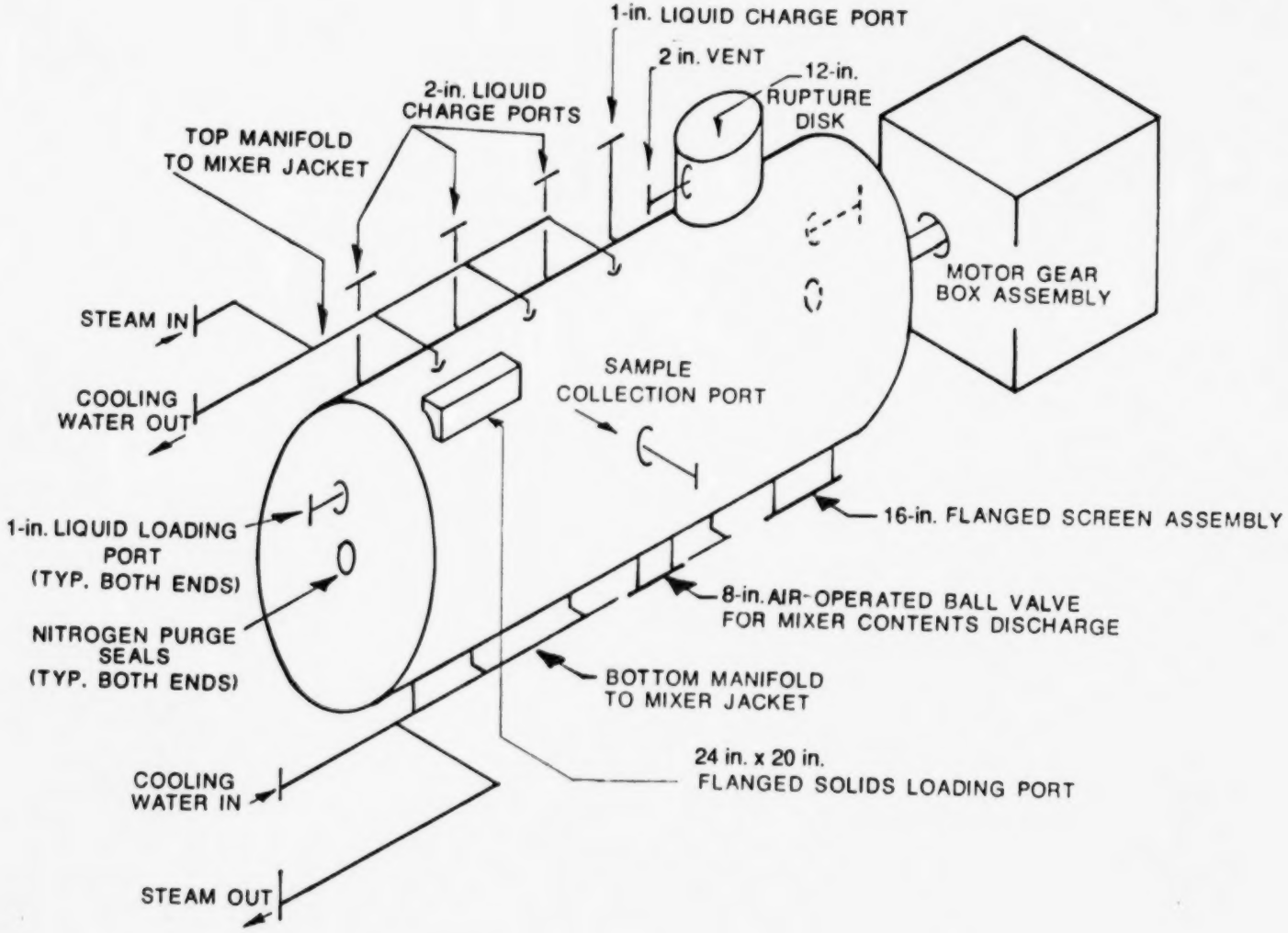

1-in. LIQUID CHARGE PORT
2 in. VENT
12-in. RUPTURE DISK
2-in. LIQUID CHARGE PORTS
TOP MANIFOLD TO MIXER JACKET
MOTOR GEAR BOX ASSEMBLY
STEAM IN
COOLING WATER OUT
SAMPLE COLLECTION PORT
1-in. LIQUID LOADING PORT (TYP. BOTH ENDS)
16-in. FLANGED SCREEN ASSEMBLY
NITROGEN PURGE SEALS (TYP. BOTH ENDS)
8-in. AIR-OPERATED BALL VALVE FOR MIXER CONTENTS DISCHARGE
BOTTOM MANIFOLD TO MIXER JACKET
24 in. x 20 in. FLANGED SOLIDS LOADING PORT
COOLING WATER IN
STEAM OUT

Figure 11. Design features of field-scale KPEG mixer.

Solids were charged into the mixer through a 20- by 24-inch rectangular flange. A 16-inch flanged screen assembly with a 2-inch drain was provided at the bottom of the mixer for draining the reagent after treatment. Treated soils were discharged from the mixer through an 8-inch air-operated ball valve located on the bottom center of the mixer.

The mixer cylinder had a steam jacket rated at a pressure of 80 psi, which is the amount of pressure exerted by steam at 156°C. Manifolds were provided across the top and bottom of the steam jacket. During heating, steam entered the top manifold, traversed downward through the jacket, and exited the bottom manifold. The manifolds were designed to serve as part of the cooling system as well. Manipulation of the valves directed cooling water upward through the jacket.

8.2.5.2 Platform--

The entire mixer/motor assembly was mounted on a platform so the discharge port would be elevated enough to allow a soil collection hopper to be placed underneath the mixer for discharge. For access, the platform was designed with catwalks around the mixer. These catwalks folded down so that legal road widths would not be exceeded during transport. The platform was designed with an integrally mounted jib crane to lift drums of soil and dry KOH for charging into the mixer.

8.2.5.3 Liquid Reagent Loading System--

The liquid-reagent loading system consisted of a pallet scale and air-operated diaphragm pump. The PEG-400 was placed on the scale and tared. The positive-displacement pump was used to charge proper quantities of PEG-400 into the mixer.

8.2.5.4 Heating System--

The heating system was a leased package steam-generating plant. Design calculations based on approximated soil and moisture contents and reagents indicated that a 600-lb/h, 80-psi unit was needed to heat the mixer contents from ambient temperature to 150°C within a 4-hour time frame. Greater steam pressure (higher temperature) could not be used because the steam jacket on the mixer was rated at 80 psi. The mixer steam manifold included a steam-pressure-relief valve specified at 80 psi.

8.2.5.5 Nitrogen System--

The nitrogen system provided in the design was part of a safety consideration in the event DMSO and TMH were not removable from the KPEG formulation. The nitrogen system consisted of a pressure regulator and flow controller. Nitrogen was purged into the mixer through the seals to provide a nitrogen atmosphere. The removal of DMSO meant the nitrogen was no longer required, and its use was discontinued when it was learned the seals would not become damaged without the nitrogen flow.

8.2.5.6 Condensate Collection System--

The design of the condensate collection system was similar to that used in the pilot-scale demonstration in Moreau. The field-scale mixer was vented

to a steel knockout tank, which was provided to collect particles of soil that may have been thrown into the vent line as a result of the vigorous mixing action. The knockout tank vented to a fan condenser, where 9600 scfm ambient air was blown over the condenser coils. The fan condenser drained into a condensate collection tank, which was originally vented into a secondary condenser consisting of a copper coil submerged in an ice bath. Because restrictions in the line size at the ice condenser created back pressure on the system, it had to be removed. The condensate collection tank was then vented directly to the activated-carbon column for collection of any remaining volatilized organics.

8.2.5.7 Process Cooling Water System--

The hot, treated soil contained within the mixing cylinder required cooling before further processing. The cooling water system of the process consisted of a 1250-gallon water tank and centrifugal pump assembly. Piping on the mixer manifolds was arranged to allow cooling water to flow upward through the mixer jacket and return to the water tank.

8.2.5.8 Reagent Collection System--

The reagent collection system consisted of two liquid-charge ports on the mixer headwalls, a 16-inch screened flange and drain on the bottom of the mixer, and two 500-gallon steel tanks immediately adjacent to the mixer. Ideally, after treatment, the soil was washed with water and the reagent was allowed to drain through the screen into the 500-gallon tanks for potential reuse.

8.2.5.9 Neutralization System--

The neutralization system consisted of a pallet scale, sulfuric acid, and a drum pump. A stoichiometric quantity of sulfuric acid was pumped into the mixer to neutralize the known quantity of KOH. The high calcium carbonate ($CaCO_3$) content of the soil required additional acid to reduce the pH of the mixer contents to a range of 6 to 9.

8.2.6 Preassembly and Transport of KPEG System to Guam

8.2.6.1 Preassembly of System in Cincinnati Warehouse--

Upon completion and approval of the system design, the necessary equipment was ordered. When the equipment arrived in a Cincinnati, the PEI crew assembled the system in a warehouse to the extent time limits permitted. Assembly was approximately 90 percent complete before disassembly was begun. Disassembly was performed systematically, and each piece was marked with appropriate field-erection notes. All of the equipment was then crated and loaded onto three flatbed tractor-trailers for transport to Port Hueneme, California.

8.2.6.2 Transport to Guam--

When the KPEG treatment equipment arrived at Port Hueneme, California, it was unloaded and placed with the appropriate reagent chemicals that had been received from a local chemical supplier.

The equipment and chemicals were then loaded onto a U.S. Navy cargo ship and shipped to the Island of Guam, U.S.A. Upon arrival in Guam, Navy personnel transferred the equipment and chemicals onto flatbed trailers and transported them to Materials Receiving, where most were again off-loaded. After passing through Materials Receiving, the equipment and chemicals were reloaded onto the flatbed trailers, transported to the site, and then off-loaded. The crated systems were moved at least nine times before they were reassembled. This movement and relocation to a site halfway around the world successfully demonstrated the portability of the field-scale KPEG system and lent credibility to the belief that larger systems can be made portable by the use of trailers dedicated to and integrally designed into the system.

8.2.6.3 System Assembly in Guam--

Upon arrival of the KPEG equipment and PEI crew at the Guam site, the crew reassembled the system with the assistance of USN PWC personnel and equipment. The first two pieces of equipment placed on site were the mixer platform and the mixer. A U.S. Navy crane, operator, and rigger were used to position the platform and mixer on top of it. When the mixer was in place, the pipe racks were laid out in the proper locations and coupled together. Other major pieces of equipment (reagent recovery tanks, sulfuric acid systems, condensate collection system, reagent weighing and pumping system, nitrogen purge system, steam generator, diesel fuel supply system, process cooling water system, air supply system, and process-water drain tanks) were then positioned. All connecting piping between the individual systems, the pipe rack, and the mixer were plumbed in. The pipes were pressurized to detect any leaks and flushed to remove any foreign debris (e.g., metal shavings, cutting oil, or corrosion) that may have accumulated.

All electrical wiring was connected. The USN PWC provided the necessary personnel and equipment to provide electrical service from the substation transformer to the system's electrical distribution panels. The electrical system was first checked out with a volt meter at each junction box and equipment connection point. All equipment was then electrically bumped to assure proper rotation and operation.

8.2.7 Process Implementation

8.2.7.1 Transport of Soil--

Because the loading of the soil was not automated, a safe and convenient method was devised for efficient manual moving of 1.5 m^3 (2 yd^3) of soil to a height of approximately 3.7 m (12 ft). Six 55-gallon drums were placed on a metal pallet that could be handled by a forklift and positioned in the metal building next to the stockpiled soil awaiting KPEG treatment. Two persons dressed in Level C protective clothing entered the building and shoveled the soil into the drums. When all of the drums were filled, the lids were placed on the drums and the pallet was swept off.

8.2.7.2 Determination of Soil Weight--

The six 55-gallon drums of soil were relocated to the scale, where a small forklift with a drum-lifting attachment placed the tared drums on the scale. The weighing of several drums during the first batch indicated that

the weight of soil per drum was fairly consistent. As a time-saving measure, it was decided that no further weighing would be performed and that 55-gallon drums filled to 90 percent capacity (50 gallons) contained 257 kg (567 lb) of soil.

8.2.7.3 Collection of Pretreatment Soil Samples--

A grab sample was collected from each of the six drums of soil, and these samples were placed in a container and mixed thoroughly to provide a homogeneous sample. Samples from this composite were placed in sample jars and properly labeled. The excess composite was returned to the stockpile.

8.2.7.4 Loading the Mixer--

The soil-loading port was approximately 3.7 m (12 ft) above the ground when the soil-loading hopper was in place. A manual jib crane was designed into the platform to hoist the 257 kg (567 lb) drums of soil to the loading hopper. Unfortunately, however, the support column for the crane was lost during shipment between Cincinnati and Guam. To facilitate loading the soil into the mixer, the U.S. Navy provided a crane and operator to hoist the drums of soil.

Three persons in Level C personal protective clothing were required to load the soil into the mixer, two on the platform at the soil-loading port and one on the ground. As the flange cover was removed from the soil-loading port, the soil-loading hopper was rigged to the crane and hoisted to the loading port. The loading hopper was bolted to the mixer flange to hold it in place.

The crane used a wrap-around drum lifter to hoist and position the drum of soil over the loading hopper. Using the manual chainfall on the drum lifter, the two persons on the platform dumped the drum contents into the mixer. This procedure was followed until all six drums of soil had been loaded into the mixer. After the loading of every second drum of soil, the mixer was turned on for a short time to disperse the soil evenly throughout the mixing cylinder.

8.2.7.5 Loading Reagent Into Mixer--

After the soil was loaded into the mixer, the components of the KPEG formulation were added. Initially, they were added at a rate of 1.0 mole of KOH and 1.0 mole of PEG-400 to provide a 1/2:1 weight relationship of mixed KPEG to soil. The KPEG formulation was later adjusted to 1.3 moles of KOH and 1.0 mole of PEG-400. The components of the KPEG mixture were still added to the soil to provide a 1/2:1 KPEG-to-soil weight relationship.

The calculations used to determine the quantities of KOH and PEG-400 required per batch did not prove to be difficult. Based on a ratio of 1.3 mole KOH to 1.0 mole PEG-400 for the KPEG formulation, the KOH and PEG-400 quantities were determined by the following equations:

Soil:

$$6 \text{ drums} \times 567 \text{ lb/drum} = 3402 \text{ lb soil} \qquad \text{(Eq. 1)}$$

Molecular weights:

PEG-400:	399	[400 less An H^+ (M.W. = 1)]
K:	39	(M.W. KOH = 56)
KPEG:	438	

Quantity of KPEG desired:

$$\frac{3400 \text{ lb soil}}{1} \times \frac{1/2 \text{ lb KPEG}}{1 \text{ lb soil}} = 1700 \text{ lb KPEG} \qquad \text{(Eq. 2)}$$

$$\frac{1700 \text{ lb KPEG}}{1} \times \frac{1 \text{ mole KPEG}}{438 \text{ lb KPEG}} = 3.88 \text{ moles KPEG} \qquad \text{(Eq. 3)}$$

PEG 400:

$$\frac{3.88 \text{ moles KPEG}}{1} \times \frac{1 \text{ mole PEG}}{1 \text{ mole KPEG}} \times \frac{400 \text{ lb PEG}}{1 \text{ mole PEG}} = 1553 \text{ lb PEG-400} \qquad \text{(Eq. 4)}$$

KOH:

$$\frac{3.88 \text{ moles KPEG}}{1} \times \frac{1.3 \text{ mole KOH}}{1.0 \text{ mole KPEG}} \times \frac{56 \text{ lb KOH}}{1 \text{ mole KOH}} = 282 \text{ lb KOH} \qquad \text{(Eq. 5)}$$

Equations 4 and 5 represent the quantities of PEG-400 and KOH pellets, respectively, that were required for each six drums of soil, 1542 kg (3400 lb), placed in the mixer for each batch of KPEG treatment.

KOH loading--After all six of the drums of soil were loaded into the mixer, preweighed KOH pellets were also loaded in the same manner. The soil-loading hopper was then removed, a new nonasbestos-type gasket was installed, and the flange cover was bolted back into place. (A new nonasbestos-type gasket was required for each batch because the original material could not retain its elasticity and was therefore unable to provide a satisfactory seal following one use.)

PEG-400 loading--When the flange was back in place, the mixer was turned on to low speed (30 rpm). The PEG-400 was loaded by pumping. A pallet of PEG-400 was placed on the scale and tared, and an air-operated diaphragm pump was used to pump the proper quantity of PEG-400 into the mixer. The mixer was then fully charged and ready for treatment.

8.2.8 Operation

8.2.8.1 Mixing--

The mixer was turned on at low speed (30 rpm) while the PEG-400 was pumped into it. When the reagents and soil were completely mixed, the mixer was turned to high speed (60 rpm). A speed of 60 rpm was sufficient to partially fluidize the mixer contents which provided greater efficiency for heat transfer. The vent line from the mixer to the condensate collection system was opened, and the fan condenser was turned on.

8.2.8.2 Heating--

The steam-generating plant was ignited, and 80-psi (156°C) steam was circulated through the mixer jacket. The mixer contents reached 150°C in approximately 2 hours. Steam pressure was reduced to 70 psi (150°C), and the temperature and mixing were maintained for a period of 4 hours. At the completion of the 4-hour period, the steam generator and mixer were shut down, the fan condenser was turned off, and the contents were allowed to cool overnight.

8.2.8.3 Washing--

During the first batch, uncontaminated soil was used to shake down the new system. Attempts were made to wash the soil with water and to drain and collect the reagent for potential reuse. Two hundred gallons of water were added to the mixer for washing and the drain on the screened flange was opened, but no drainage occurred. The screen was then back-flushed to remove any plugging, but still no draining occurred. When the top flange was opened, it was found that the soil had settled, and the reagent was not filtering through the soil as it had in the Moreau pilot-scale demonstration. The supernatant was pumped out of the mixer and into a 500-gallon reagent tank. The reagent was neutralized with sulfuric acid, collected by the U.S. Navy Public Works Center (USN PWC) liquid-waste hauler, and transported to the sanitary sewer treatment plant. The soil was also neutralized with sulfuric acid and discharged into a soil-collection hopper for storage. A decision was made to discontinue soil washing and reagent recovery during the field-scale demonstration. It was decided that treated soil would be neutralized with sulfuric acid, discharged into a steel collection hopper, and then stored until EPA approval for its final disposal.

8.2.8.4 Neutralization--

Cooling of the mixer contents was required prior to neutralization because of the strong exothermic reaction anticipated. Overnight cooling lowered the temperature of the mixer contents from 150° to 90°C. Additional cooling was achieved by recirculating the cooling water upward through the mixer jacket until the mixer contents were cooled to 50°C. The cooling water was kept running, and a stoichiometrically predetermined quantity (200 lb) of sulfuric acid was added in 20-lb increments. Because of the high calcium carbonate content in the Guam soil, additional sulfuric acid was required to adjust the pH to a range of 6 to 9. Samples were collected from the sample-collection port, and the slurry pH measured. Additional 20-lb increments of

sulfuric acid were added and the pH measurement process repeated until the pH was within the 6 to 9 range. A total of 280 lb of sulfuric acid per batch was required to neutralize the mixer contents.

8.2.8.5 Posttreatment Soil Samples--

The collected sample found to be within the 6 to 9 pH range was also used as the posttreatment soil sample. This sample was distributed into the appropriate sample jars and properly labeled. Any excess samples taken during neutralization were returned to the discharge hopper.

8.2.8.6 Mixer Discharge--

With the soil collection hopper in place and the mixer operating at low speed (30 rpm), the 8-inch, air-activated, discharge ball valve was opened from the mixer control panel. The mixing action of the mixer moved its contents to the discharge valve for removal. Mixer contents were discharged within 10 minutes. The air-activated ball valve then was closed and the mixer turned off.

8.2.9 Storage of Treated Soil

The treated soil and the reagents used in the treatment process were discharged into the soil-collection hoppers pending analytical results. The filled soil collection hopper was removed from beneath the mixer discharge, and the lid was bolted on. The soil collection hopper was then placed in an area designated for storage of treated soil. This storage area was located within the hot zone in the event of a spill from a soil collection hopper batch that failed to meet the R&D permit requirements. Before PEI's final departure from the site, all soil hoppers containing KPEG-treated soil were positioned within the metal building.

8.2.10 System Decontamination and Disassembly

A high-pressure (2000 psi) water washer was leased for decontamination of the process equipment. Although no PCB and PCDD contaminants were believed to remain inside the mixing cylinder, the inside of the cylinder was high-pressure washed. The decontamination water was collected in 55-gallon drums. The external portion of the mixer, the platform, and all other ancillary equipment in the hot zone were also similarly decontaminated. The equipment located outside the hot zone was also rinsed with the high-pressure water washer. All decontamination water was pumped from the concrete containment area into a collection tank, and the concrete was then pressure washed as well. Again, the wash water was pumped into a collection tank. All collected decontamination water was held for processing, as described in Subsection 8.2.11.

The KPEG treatment system was then disassembled and prepared for shipment to the U.S. mainland in accordance with procedures indicated by EPA's Task Project Monitor. All major equipment items were disconnected from the system and staged so the system would be ready for crating by U.S. Navy personnel and transport back to the U.S. mainland.

8.2.11 Treatment of Collected Condensate and Decontamination Water

As part of the complete KPEG field-scale demonstration system, a small treatment system was included for decontamination of process water. The collected condensate and decontamination water were passed through a series of cartridge filters and activated-carbon canisters. The treated water was collected, sampled, and held until analytical results for PCB contamination were obtained. Treated waters with nondetectable PCB concentrations were either collected by the liquid transport truck and discharged into the sanitary sewer treatment plant or pumped back onto the hot zone.

8.2.12 Analytical Results

Analyses for PCBs were performed by U.S. EPA/RREL personnel in the U.S. Navy's field laboratory near the USN PWC site (FENA Laboratory). The method used in the field laboratory was one that U.S. EPA/RREL developed for the quantitation of PCBs in soils. The method was designed to use gas chromatographic-mass spectrometric equipment available in the Navy's field laboratory on Guam. This method was regarded as a field-screening method, and the corroborative analyses were performed by the laboratory at IT/Knoxville. The procedure used in the field Laboratory in Guam entailed extracting the PCBs from the sample matrix and quantitating them in the extract with a gas chromatograph/mass spectrometer (GC/MS). This method used the Dry Color Manufacturers Association (DCMA) PCB standard to prepare calibration curves for use in quantitating the residual PCB congeners, as stipulated in the R&D Permit.

The IT/Knoxville laboratory used a more rigorous procedure previously developed for EPA to analyze for PCBs. The corroborative analyses were implemented to confirm results obtained in the field laboratory. The soil samples were prepared and analyzed by gas GC/MS with a modification of the method developed for EPA entitled "Analytical Method: The Analysis of By-Product Chlorinated Biphenyls in Air, Revision 2," published on May 20, 1985. Samples were analyzed with the same frequency specified for the quantitation in the field.

Results of the analyses of untreated Guam soil in the field laboratory and those of the corroborative analyses at IT/Knoxville differed somewhat. The PCB concentrations of the untreated soil from the corroborative analyses were reported as recovery corrected. Onsite PCB concentrations of the untreated soil were not recovery-corrected when reported, which explains the consistent discrepancy between the results at the two laboratories. Table 16 presents the analytical results of the KPEG field-scale demonstration performed in Guam.

A review of treated-soil analytical data from both laboratory facilities indicated that the destruction of the total PCB concentration exceeded 99 percent. In both sets of data, analysis of each of the congener peaks showed that the tetrachlorobiphenyl congener concentration in a portion of the treated batches was slightly above the R&D permit requirement of 2 ppm or lower per PCB peak. Additional laboratory work on the once-treated soil showed that changing the ratio of KOH:PEG-400 from 1.0 to 1.3 while maintaining the ratio of PEG-400 to soil the same as in the initial dechlorination

TABLE 16. CONCENTRATIONS OF PCBs FOUND IN PRE- AND POST-TREATMENT GUAM SOILS, CONDENSATE, AND KPEG REAGENT, AND PERCENTAGE REDUCTIONS ACHIEVED FOR SOILS

Batch No.	Initial PCB Concentration in soil		Concentration of PCB in soil following treatment		Percentage reduction (using Lab 2 data)	Concentration of PCB's found in condensate (using Lab 2 data)	Concentration of PCB's found in recovered reagent (using Lab 2 data)
	Lab 1	Lab 2	Lab 1	Lab 2			
1	1990[a]	3276[a,b]	15.2	13.9[b]	99.5757	0.831	0.01
2	1740	3828	1.99	1.01	99.9736	0.176[c]	0.14
3	1490	3406	1.45	2.86	99.9160	-[c]	0.56
4	1540	3778	1.94	3.03	99.9198	13.81	-
5	1010	3651[b]	1.91	3.31	99.9093	3.50	-
6	1410	3260[b]	4.38	7.77	99.7617	125[d]	-
7	1140	-[e]	3.48	8.56	-	-	-
8	1860	-[e]	4.94	f	-	-	-
1-R[g]	15.2	-	0.48	-	96.84	ND[h] (1.0)	-
6-R	4.38	-	0.85	-	80.60	ND (1.0)	-
7-R	3.48	-	0.15	-	95.69	ND (1.0)	-
8-R	4.94	-	0.66	-	86.64	ND (1.0)	-

[a] The concentrations reported by Laboratory 2 are recovery-corrected. The initial PCB concentrations reported by Laboratory 1 are not corrected for recovery for Batches 1-8; therefore, these values are low when compared with the low-resolution recovery-corrected values obtained by Laboratory 2. These data were obtained by use of extraction and gas chromatography/mass spectrometry.

[b] Average of duplicate analysis.

[c] Composite of condensate resulting from treatment of Batches 2 and 3.

[d] Average of triplicate analyses.

[e] Not analyzed.

[f] Inordinately high value was disregarded.

[g] Batches of soils that were retreated.

[h] ND = none detected.

reactions led to almost 100 percent degradation of all PCBs, including the resistant tetrachlorobiphenyl isomer.

Following treatment, each batch of treated soil was contained in individual soil collection hoppers. The batches containing greater than 2 ppm of tetra congener were loaded back into the mixer, mixed with the new KPEG formulation of 1.3 moles KOH and 1.0 mole PEG-400, and retreated. Analytical results obtained for the retreated batches indicated the tetra congener in each batch was well below 1 ppm.

Based on the results obtained in both the field laboratory and the corroborative laboratory analyses, all the PCB congener concentrations in the treated Guam soil were less than 2 ppm and the final pH was within the range of 6 to 9.

8.2.13 Discussion of Quality Assurance and Quality Assurance Goals

8.2.13.1 Verification of Extraction Methodology, Evaluation of Accuracy--
The analytical methods used in the field (near the Guam site) and in IT's Knoxville laboratory are described in detail in the Quality Assurance Project Plan (QAPjP) entitled "Quality Assurance Project Plan for Field Test of a KPEG Reactor for Chemically Degrading PCB in Contaminated Soil and Spent Transformer Oil Located at the U.S. Naval Public Works Center at Guam," which was prepared and approved by EPA. The quality assurance data gathered in conjunction with performing IT's corroborative analyses are discussed in detail in the following paragraphs.

Sample extracts were analyzed by use of high-resolution gas chromatography/low-resolution mass spectrometry (HRGC/LRMS) in the selected ion monitoring mode for enhanced sensitivity. The column used for this was a 60-m, DB5, fused-silica capillary column. The following ions were monitored for in each homologous group.

Group	Masses Monitored
Mono	188,190
^{13}C-Mono	194,196
Di	222,224,226
Tri	256,258,260
Tetra	290,292,294
^{13}C-Tetra	302,304
Penta	324,326,328
Hexa	358,360,362
Hepta	394,396,398
Octa	428,430,432

Group	Masses Monitored
^{13}C-Octa	440,442
Nona	462,464,466
^{13}C-Deca	510,512

Response factors (RFs) were calculated for each representative PCB isomer relative to ^{12}D-chrysene, which was monitored at a mass of 240. A five-point calibration plot was run in triplicate. The mean response factors obtained from this 15-point calibration curve were used for all subsequent calculations (see Appendix Table A-1). The mono-PCB RF is the mean of individual RFs from 2-mono and 4-mono biphenyl. A four-point calibration curve was used for mono, di, and trichloro-PCBs because the mass spectral output was off-scale at the highest calibration solution. The shift standards were analyzed at the start and end of each 12-hour shift, and these produced response factors within 30 percent of the multipoint mean RF values calculated from the 15-point calibration curve. Appendix Tables A-2 through A-10 provide continuing calibrations for each batch of samples.

The sample extraction method for soils stipulated in the QAPjP was a 16-hour Soxhlet extraction with hexane. Because of the amount of time involved in performing this type of extraction, however, IT's lab compared the efficiency of Soxhlet extraction with a method referred to as "jar extraction," wherein hexane is added to the sample contained in a glass bottle, which is then agitated for a minimum of 3 hours. Four pairs of samples were analyzed for comparison of the methods. For this test, two sets of initial (pretreatment) soils and two sets of final (posttreatment) soils were extracted. One sample from each set was extracted by the Soxhlet method, and the other sample was extracted by the jar method. Appendix Tables A-11 through A-14 show the results of this comparison. The results indicated that the methods were comparable; therefore, it was decided that the remainder of the samples received from the KPEG project would be extracted by the jar method.

In addition, analyses were performed to verify that the jar method was efficient in the sense that it extracted all available PCBs from each soil sample. This was verified by extracting the same sample twice by the jar method. Analytical results indicated that one application of the jar method extracted 99 percent of the extractable PCBs. Appendix Table A-15 shows the results of this test of the efficiency of the jar method.

In the preceding test for accuracy, the analyst is only evaluating extractable PCBs, as one cannot be certain of the total amount present in an actual sample. As a further check on the accuracy of the method, IT split three soil samples and analyzed them before and after adding known concentrations of the following PCB isomers:

Mono - 2-PCB	Penta- 2,2',3',4,5 PCB
Mono - 4-PCB	Hexa - 2,2',3,4,5,6' PCB
Di - 2,4 PCB	Hepta- 2,2',3,4,4',5', 6 PCB
Tri - 2,4,6 PCB	Octa - 2,2',3,3',5,5',6,6' PCB
Tetra- 2,2',4,6 PCB	Nona - 2,2',3,3',4,4',5,5'6,6' PCB

Appendix Tables A-16 through A-19 present the results of these analyses, including percentage recoveries. With one exception (monochlorinated biphenyl), the percentage recovery values obtained for soils all fell within the stipulated range. The percentage recoveries obtained for the PCB isomers added to the condensate sample were generally not within the desired range because of the high levels of PCBs present in the sample at the time of spiking.

8.2.13.2 A Comparison of EPA vs. IT Results--

Because it was necessary to obtain immediate results, some of the analyses of soils, KPEG reagent, and condensate were performed by EPA chemists working in Guam. The primary purpose of these analyses was to aid in day-to-day operation of the KPEG reactor. For comparison of the onsite data with the IT lab data, the data obtained by the EPA onsite lab are provided in Table A-20 in the Appendix. The corresponding IT sample numbers for Batches 1 through 6 are as follows:

	Initial Soil	Final Soil
Batch No. 1 -	BB0434	BB0438
Batch No. 2 -	BB0436	BB0432
Batch No. 3 -	BB0440	BB0485
Batch No. 4 -	BB0441	BB0479
Batch No. 5 -	BB0442/BB0443	BB0478
Batch No. 6 -	BB0446	BB0477
Batch No. 7 -	Unavailable	
Batch No. 8 -	Unavailable	

Appendix Table A-21 provides a comparison of the results from the EPA lab on Guam with those from the IT Lab in Knoxville.

8.2.14 Summary of QA/QC Procedures Used by IT-Knoxville for Analysis of PCB Samples From the Guam KPEG Project

The accuracy, precision, and blank data collected during the analyses of the Guam samples are summarized in the first three subsections that follow. In addition, the quality assurance objectives listed in the QAPjP for the project are shown in Table 17, and the quality assurance data corresponding to each of these objectives are discussed in the remaining subsections under this heading.

8.2.14.1 Accuracy--

All samples were spiked with carbon-13-labeled PCB surrogate standards. Percentage recoveries for each of the carbon-13-labeled surrogates are listed

TABLE 17. QUALITY ASSURANCE OBJECTIVES FOR PRECISION, ACCURACY, COMPLETENESS, AND METHOD DETECTION LIMITS

Critical measurement	Units[a]	Stream description	Analytical method	MDL[b]	Precision[c]	Accuracy[d]	Completeness, %
Weight (soil, KPEG components), NIXTOX drum	Pounds	KPEG components, soil	Balance	0.1	+10%[e]	<10%[e] (bias)	100
PCB concentration	ppm	Soil pretreatment and posttreatment	f	0.5	40% RDS	20-150%	80
PCB concentration	ppm	Duplicate analysis of extract[g]	f	0.5	40%	-	80
PCB concentration	ppm	Composited water washes, acid washes	f	0.5	40[h]	20-150%	80
PCDD and PCDF concentration	ppb	Oil or soil, pretreatment and posttreatment	EPA 8280	0.1 ppb	40	20-120%	80
Temperature	°F (°C)	Reactor	Thermistor or thermocouple	-	±2° (1°)	±5° (3°)[e]	80
PCB	ppm	Condensate	f	0.5	40[h]	20-150%	80
PCB	ppm	Used KPEG	f	0.5	40[h]	20-150%	80
PCB	ppm	Oil pretreatment and posttreatment	f	0.5	40% RSD	20-150%	80
PCB	ppm	Duplicate analysis of oil extract[g]	f	0.5	40[h]	-	80
pH	pH units	Water, soil	EPA 150.1	-	±0.1[e,i]	±0.1[i] (bias)	90
Moisture	%	Soil	EPA 3550	-	±10[e]	<10% (bias)	100

[a] ppm = parts per million or mg/kg; ppb = parts per billion or mcg/kg.

[b] ppm unless otherwise indicated. The value listed for PCB concentration is 0.5 ppm per each PCB component.

[c] Precision expressed as relative percent difference of field duplicate unless specified otherwise.

[d] Accuracy expressed as percent recovery of matrix spike unless specified otherwise.

[e] Estimated.

[f] The method developed by Dr. A. Kornel USEPA/HWERL will be implemented.

[g] One sample extract per batch of 12 or less samples will be analyzed in duplicate to obtain data indicative of the precision of the instrumental method of quantitation.

[h] Estimated based on pesticide matrix spike recoveries from soil. Test Methods for Evaluating Solid Waste, SW846, 1986, Chapter 1, page 40.

[i] Absolute difference in pH units of duplicate measurements; difference in pH units of a measured value and the accepted value of a laboratory control standard.

in Appendix Tables A-22 through A-26, which present a summary denoting extraction efficiencies obtained for each sample matrix. These matrices included initial (pretreatment) soil, final (posttreatment) soil, condensate water, spent KPEG reagent, and unsettled suspensions of treated soil and liquid taken directly from the reactor. Condensate samples were collected from the knockout (primary settling) tank and the secondary collection tank (or fan tank). These aqueous samples were spiked with carbon-13 surrogates and then triple-extracted by use of methylene chloride as the solvent. Results for aqueous samples were reported in parts per billion (ppb), whereas results for soil samples were reported in parts per million (ppm). Samples of the highly alkaline, posttreatment KPEG reagent were first neutralized to a pH of 5 to 7 and extracted. Once again, methylene chloride was the solvent. These samples were spiked in the same manner as the condensate samples, and results were reported in parts per billion.

8.2.14.2 Evaluation of Precision--

Precision of the overall analytical method was evaluated by performing duplicate extractions and analyses on a split pretreatment soil sample. Duplicate aliquots of soil were extracted (by the jar method), and the extracts were then analyzed separately. These samples showed a variance of 6.9 percent in total PCBs. Appendix Table A-27 presents data from this test. In addition to the analysis of the duplicate samples, which evaluated the overall precision of the extraction method and the GC/MS quantitation method, five sample extracts were analyzed by performing duplicate injections. Appendix Tables A-28 through A-32 summarize the results. The average of the Relative Percent Differences obtained was well below the limit stipulated in the QAPjP, i.e., 40 percent.

8.2.14.3 Blanks--

Reagent blanks were analyzed to assess the purity of the reagents used for the analyses. The number of blanks analyzed exceeded the prescribed number of 1 blank per 12 samples stipulated in the QAPjP. Summaries of the results are shown in Appendix Tables A-33 and A-34. Table A-33 gives the results of the reagent blanks run using only the drying agent sodium sulfate. These blanks were extracted and analyzed in the same manner as the soil samples, and results are reported in parts per billion. The results given in Table A-34 are for blanks prepared from deionized water. These blanks were extracted and analyzed in the same manner as the samples of condensate and KPEG reagent. These results are reported in parts per trillion (ppt).

8.2.14.4 Weight Measurements--

The weights of the KPEG components were measured at the Guam site by means of an electronic scale. This scale had a capacity of 5000 pounds and a digital display incremented in units of 5/10 of a pound. The scales used for this project were Flexweigh Model DWM IV weight indicators with 48-inch by 48-inch Flexure base platforms. Each of the two balances was calibrated by the supplier before being shipped to Guam. Upon arrival of the balances in Guam, the accuracy was confirmed by placing items of known weight on the platforms to establish that the balances were still properly calibrated.

Constant surveillance of accuracy and precision was maintained by weighing each set of four drums of PEG and the pallet upon which they rested before adding them to the reactor. It was determined through repeated weighings that four drums of PEG and a pallet would weigh 2100 pounds, and the consistency of these results verified that the scales remained in calibration. All reactants that were added to the reactor were weighed prior to their addition.

8.2.14.5 PCB Concentration in Pretreatment Soils--

Method detection limit--The method detection limit (MDL) specified in the QAPjP is 0.5 ppm per PCB component. The MDL was achieved for each congener group in the analyses of the pretreatment samples, with the exception of trichloro-PCB and decachloro-PCB. Trichloro-PCB was not detected in any of the pretreatment soil samples, but the detection limit was above 0.5 ppm in 11 of 11 analyses. The range of the MDLs for the trichloro-PCB was 0.56 to 3.0 ppm, for an average of 1.58 ppm. Decachloro-PCB was not detected in 6 of 11 analyses. Detection limits for this compound were 0.63 to 1.4 ppm, with a mean of 0.94 ppm.

Precision--Precision was to be less than or equal to 40 percent relative standard deviation (RSD). Precision calculated for the pretreatment soil analyses was checked in two ways. In one test for precision, a sample was split and each aliquot of soil was extracted and analyzed. As indicated in Appendix Table 1, the precision for these duplicate analyses shows a relative percent difference of only 6.9. In addition, the precision was calculated for the percentage recoveries of the surrogate standards that were added to all samples. The percent recoveries of the four carbon-13-based surrogates are shown in Appendix Table A-23. The RSD values obtained ranged from 3 to 22 percent. All values were well within the 40 percent RSD required.

Accuracy--Accuracy was to be within the range of 20 to 150 percent, as determined by the percentage recovery of the surrogates spiked into each sample. Only the results for the decachloro-PCB were found to fall outside of this range. For the pretreatment soils, 5 of 11 samples proved to be above 150 percent; these were BB0452DI at 163 percent, BB0446DI at 155 percent, BB0435 at 184 percent, BB0437 at 162 percent, and BB0437DI at 165 percent. The high values for decachlorinated PCB surrogates may be attributed to the difficulty inherent in the chromatography of the heavier molecules.

Completeness--With regard to data completeness, the IT lab analyzed at least one pretreatment soil sample per batch as was stipulated in the QAPjP.

8.2.14.6 PCB Concentrations in Posttreatment Soils--

The posttreatment soils did not show any outliers in either the detection limits or the percentage recovery of matrix spikes. This was possibly due to the elimination of the interferences found in heavily contaminated samples, an example of which would be the pretreatment soils.

In terms of completion, five of the six batches of posttreatment soils were analyzed by the IT Lab. This represents 83 percent of the total and thus exceeds the 80 percent prescribed in the QAPjP.

8.2.14.7 Duplicate Injection of Soil Extracts--

Detection limits in samples of condensate and KPEG Reagent, were all within prescribed limits for precision and accuracy. When performing the duplicate injections of the soil samples, however, one of three soil samples showed a percent difference greater than the 40 percent limit imposed in Table 3-1 of the QAPjP. The IT sample BB0437DI (pretreatment soil) showed a difference of 77 percent in the reported amounts of tetrachloro-PCB. This was possibly due to the heavy concentrations of assorted PCB isomers found in the pretreatment samples.

8.2.14.8 PCB Contamination in KPEG Reagent Prior to Addition of Soil--

No analyses were done on the KPEG reagent before its use in the reactor. All components used in the preparation of the reagent were of high grade and assumed to be free of PCB contamination.

8.2.14.9 PCB Concentration of Composited Water and Acid Washes--

The water/acid wash step of the KPEG process was eliminated; therefore, no samples could be taken.

8.2.14.10 PCB Concentration in Condensate--

Condensate samples were collected from two sources--the "knockout" tank and the "fan cooled condensor" tank. The knockout tank was a primary settling tank. Material from this source was primarily aqueous, but it also contained small amounts of treated soil and used KPEG reagent. Water from the fan tank did not contain appreciable extraneous material. Condensates from both sources were extracted in the same manner, and results were reported in parts per billion. Approximately 40 to 60 gallons of condensate were collected from each batch. Based on Batch 4 as an example, the initial PCB concentration of the 3400 lb of soil charged into the mixer was 3778 ppm; thus, the total quantity of PCB can be calculated by Equation 6:

$$\text{Total lb PCB in soil} = \text{soil} \times \frac{\text{lb PCB}}{\text{lb soil}} \qquad (6)$$

Placing Batch 4 values into Equation 6 indicates that 12.8 lb of PCB were contained within the batch. Analysis of the condensate from Batch 4 indicated a PCB concentration of 13.81 ppm. The total quantity of PCBs in the condensate can be calculated by Equation 7:

$$\text{Total lb PCB in condensate} = \frac{\text{Gal condensate}}{1 \times 10^6} \times \text{PCB conc. (ppm)} \times 8.34 \qquad (7)$$

Again based on values obtained from Batch 4, the total quantity of PCBs transferred from the soil to the condensate was 0.006 lb of PCBs. Therefore, the total quantity of PCBs transferred from the soil in the mixer to the condensate was less than 0.04 percent of the overall quantity, which ensured that the reduction of PCBs in the soil was not the result of PCB relocation into the condensate by steam stripping.

Precision and accuracy for these samples were within the prescribed limits set forth in the QAPjP. The number of samples required for completion exceeded the 80 percent required in the QAPjP for condensate. One of the samples, BB0447 (material from the knock-out tank), was a composite taken from the accumulation of Batches 1, 2, and 3.

8.2.14.11 PCB Concentration in Used KPEG Reagent--

The treated soil is actually a mixture of soil and the KPEG reagent. In the case of Batches 1, 2, and 3, however, a supernatant layer of PEG was observed in the hopper after treatment. The total PCB concentrations were 0.0114, 0.136, and 0.56 ppm, respectively, in samples of these three liquids. Prior to analysis, the used KPEG reagent was neutralized and then extracted with methylene chloride. Precision and accuracy were within the limits prescribed in the QAPjP. Reagent from only three of the six batches was sampled for 50 percent completeness. The QAPjP called for 80 percent. The probable reason the other three samples were not taken was a tight budget and the fact that no significant levels of PCBs were found in any of the KPEG from the first three batches of treated soil.

Because the water washes were eliminated from the process, separation of the reagent and soil was not performed. The soil and reagent mixtures were discharged together into 2-cubic-yard collection hoppers for individual batch storage.

8.2.14.12 PCB Concentrations in Oil (Pre- and Posttreatment)--

No oil was treated; therefore, no samples could be taken or analyzed.

8.2.14.13 Duplicate Analysis of Oil Extract--

No oil was treated; therefore, no samples could be taken or analyzed.

8.2.14.14 Measurement of pH in Water and Soil--

Because of difficulties encountered in the use of a pH meter (arising from the consistency of the product and the tropical climate), pH paper was used exclusively.

8.2.14.15 Measurement of Soil Moisture--

Soil moisture was not measured.

8.2.15 Results Obtained in Quantitating Polychlorinated Dioxins and Polychlorinated Dibenzofurans

Wright State University performed these analyses in accordance with Method 8280, as described in the compilation of methods included in SW 846.

The concentrations of each congener group (tetrachlorinated through octachlorinated dibenzo-p-dioxins and dibenzofurans) are listed in Appendix Table A-35. Concentrations of 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) and 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF) that were found in the samples are shown in Appendix Tables A-36 and A-37, respectively. Appendix Table A-38 indicates the percentage recoveries obtained for the Carbon-13-labeled internal standards.

As shown in Appendix Table A-35 and the Chain-of-Custody Form (Table A-39), four samples were analyzed for tetrachlorinated through octachlorinated dibenzo-p-dioxins (PCDDs) and tetrachlorinated through octachlorinated dibenzofurans (PCDFs). Samples 7A and 8B, which are aliquots from Soil Batches 7 and 8, were taken prior to the second KPEG treatment. Samples 7D and 8D were taken from the same two batches of soil following the second treatment with KPEG. No tetrachlorodibenzodioxins (TCDDs), including 2,3,7,8-TCDD, were detected in any of the samples. Octachlorodibenzo-p-dioxin was found in Samples 7A and 7D; however, this finding is questionable because this highly chlorinated compound would readily dechlorinate under conditions of the KPEG treatment. Although TCDFs were found in all four samples, the levels of 2,3,7,8-TCDF remaining after the second treatment with KPEG were 0.23 and 0.09 ppb, respectively. Traces of PeCDF were found in the batches of twice-treated soil, but, again, the levels were at or below the 1-ppb level. Hexachlorodibenzofuran was found only in Samples 7A and 7D; however, these findings are at the limit of detection (approximately 0.02 ppb). No other PCDFs were found in these samples.

Quality assurance data are also included in Appendix Tables A-35 through A-38. The laboratory blanks analyzed concurrently with the quantitation of total PCDD and PCDF congeners and the 2,3,7,8-TCDD and 2,3,7,8-TCDF isomers contained no detectable levels of these compounds (limits of detection were well below 1 ppb).

The accuracy of these measurements is indicated by the percentage recoveries obtained for the internal standards. All fall within the limits of 20 to 120 percent stated in the QAPjP. For 2,3,7,8-TCDD, five analyses, including a lab blank, resulted in a range of 35 to 95 percent recovery for the $^{13}C_{12}$-2,3,7,8-TCDD internal standard and a mean of 70 percent, with a standard deviation of 26 units. Five analyses for 2,3,7,8-TCDF, including a lab blank, resulted in a range of 42 to 118 percent recovery for the $^{13}C_{12}$-2,3,7,8-TCDF internal standard and a mean of 73 percent, with a standard deviation of 28 units.

The precision of these analyses can be assessed by calculating the relative standard deviation for the percentage recoveries of the Carbon-13-labeled internal standards. These values (shown in Appendix Table A-38) range between 47 and 113 percent. All fall well within the limits specified in the QAPjP.

Analyses of the five samples for 2,3,7,8-TCDD did not reveal any of this compound. Detection limits ranged from 0.0178 to 0.0269 ppb. Analysis for 2,3,7,8-TCDF revealed that low concentrations (0.09 to 3.5 ppb) of this compound were present in all samples except the lab blank, which had a detection limit of 0.0054 ppb.

The completeness of the data is 100 percent. Four samples plus one blank were successfully analyzed.

SECTION 9

COST ANALYSIS OF THE KPEG PROCESS

Discussions in the preceding sections have dealt with the KPEG technology, the fundamental principles behind the KPEG chemical degradation process, and various techniques used in its application. The analytical results presented indicate that the KPEG degradation process offers a potentially suitable treatment alternative for matrices contaminated with PCBs and other chlorinated or halogenated aromatic compounds. For the KPEG process to be attractive to potential clients, it must compete economically with current treatment/disposal practices or offer distinct advantages. One advantage of this process is its ability to degrade chlorinated dioxins and chlorinated dibenzofurans, both of which are banned from landfilling and currently cannot be incinerated in the United States because of a lack of permitted incinerators. The disposal mechanism currently used for matrices contaminated with these compounds is secure on-site storage.

9.1 KPEG TREATMENT COSTS FOR THE GUAM DEMONSTRATION

The KPEG treatment system demonstrated on the Island of Guam, U.S.A., represented the first attempt to operate this process at a scale approaching full scale. It included the use of conceptual process equipment and operations that had not been demonstrated during smaller-scale studies. This field-scale unit consisted of a mixer with a 480-gallon working capacity. The largest mixer type system previously used for the KPEG demonstrations was a unit with a 40-gallon capacity at the Moreau, New York, site. Thus, this effort represented a scale-up greater than an order of magnitude.

Table 18 presents the costs of the equipment in the Guam KPEG demonstration. As indicated in this table, many of the major equipment items were leased rather than purchased to minimize the capital expenditures as well as the amount of EPA equipment left over after the demonstration. In 1988, the capital expenditure was $229,000 for equipment items directly related to the system and its assembly. Costs involved in leasing equipment were as follows: the steam-generating plant ($900/month), two sets of electronic scales ($220/month each), an air compressor ($350/week), and two fork lifts ($1130/week total). The initial assembly of the system which took place in a Cincinnati-based warehouse over a period of 2 months, involved the use of two to six personnel at any given time throughout the system's assembly. The system was approximately 90 percent assembled before it was disassembled and crated for transport. The cost of the assembly in Cincinnati, including all labor, expenses, and contractor profit, was $64,000. The cost of transporting the

TABLE 18. EQUIPMENT COSTS FOR 2-TON KPEG SOIL TREATMENT SYSTEM USED IN GUAM DEMONSTRATION[a]
(1988 dollars)

Equipment	Purchase cost	Lease cost
Soil-loading forklift		770/wk[b]
Reagent feed		
Scale		220/mo[c]
Pump	1,550	
Steam generating		
Steam-generating plant		900/mo[c]
Fuel oil tank	150	
Condensate collection		
Condensate Tank 1	350	
Condenser	2,100	
Condensate Tank 2	150	
Condensate treatment	500	
Process cooling		
Process water tank	1,300	
Process water pumps	3,500	
Mixer system		
Mixer	149,350	
Platform	18,000	
Soil-loading hopper	750	
Mixer insulation	2,300	
Neutralization		
Scale		220/mo[c]
Drum pump	750	
Soil removal		
Soil removal hoppers (30)	17,850	
Miscellaneous		
Small forklift		360/wk[b]
Air compressor		350/wk[b]
Diaphragm pumps (2)	3,100	
Piping system	20,100	
Electrical system	7,200	
Total	229,000	1815/wk

[a] Costs obtained from actual equipment purchase orders and invoices.

[b] Equipment leased from vendors on the Island of Guam.

[c] Equipment leased from vendors on U.S. mainland.

equipment from Cincinnati to Port Hueneme on three 40-foot flatbed trailers was $16,000. The U.S. Navy transported the equipment from Port Hueneme to the Guam site at no charge.

When the equipment and crew of six arrived in Guam, the setup of the system and its final installation took 2 weeks and cost $16,000. This included all labor, overhead, and profit, but not the indirect per diem expense of the crew ($92/day per person) during the 2-week period, which totaled $7728.

As is the case with any pioneering system, operation of the KPEG system was expensive because it involved exploration into the unknown. Costs were further elevated because the site of the operation of the field-scale system was half-way around the world. The operational costs presented in Table 19 represent the labor of three contracting personnel who were used during the second trip to Guam. Indirect costs, such as the $122 per diem for each person (an increase of $30 per day over the first trip) and the auto rental costs, are included to indicate the total costs; however, these were omitted prior to calculating a direct per-ton operational cost. Also, costs of leasing the capital equipment in Table 18 are not included in the per-unit operational costs.

9.2 PROJECTED FULL-SCALE KPEG TREATMENT COSTS

The operating data collected during the Guam KPEG demonstrations were compiled and given to an independent engineering firm for performance of an economic analysis of a full-scale system. Battelle Laboratories in Columbus, Ohio, was the firm selected by the Naval Civil Engineering Laboratory (NCEL). Battelle's completed economic evaluation was presented to the NCEL in Port Hueneme, California, on February 17, 1989, in a report entitled "Final Report on Evaluation Process To Chemically Treat PCBs and Hazardous Materials." This section presents details of Battelle's evaluation for a full-scale 50-cubic-yards/day system.

9.2.1 Process Description

Figure 12 is a flowsheet of the KPEG process design developed for this evaluation. The process is divided into the following sections:

Section 100 -- Feed Preparation
Section 200 -- KPEG Reactor
Section 300 -- Neutralization
Section 400 -- Ancillaries

9.2.1.1 Feed Section (100)--

Contaminated soil from a storage pile is brought into the plant on a conveyor (102) and screened on a vibrating screen (101) to remove rocks (the size fraction is a function of PCB distribution by particle size). The rocks are transported to a rock pile on a conveyor (103). The undersized fraction is transferred on a conveyor (104) to a soil charge hopper (105). PEG is transferred (108) from a storage tank (106) to a KPEG charge tank (110). A

TABLE 19. TREATMENT COSTS FOR 2-TON KPEG SOIL TREATMENT SYSTEM UTILIZED FOR GUAM DEMONSTRATION

Operational Parameters

- One 3400-lb (1.7-ton) batch/10-h shift
- One 3400-lb (1.7-ton) batch/day
- Three personnel/day
- Capital investment: $229,000

	Unit cost, $	Quantity per 1.7-ton batch	Treatment cost, $/1.7-ton batch
DIRECT COSTS			
Chemicals			
PEG-400	0.4514/lb[a]	1550 lb	699.67
KOH (dry)	0.6150/lb[b]	285 lb	178.45
H_2SO_4	0.1133/lb[c]	280 lb	31.72
Activated carbon	2.45/lb	0.20 lb	0.49
			910.33
Utilities			
Electricity	0.0901/KWH[d]	90 KWH	8.11
Fuel oil	1.00/gallon[d]	50 gallons	50.00
Water	Nominal[d]	Nominal	Nominal
			58.11
Labor (direct)			
Operators	2/day at $35/h (fully burdened) at 10 h/day		700.00
Manager	1/day at $45/h (fully burdened) at 10 h/day		450.00
			1150.00
Safety Equipment			
Personnel protective clothing, 3 changes/batch at $20/change			60.00
Total direct operating costs per batch			2178.44
Direct operating cost per ton			1281.43

(continued)

TABLE 19 (continued)

Item	Unit cost, $	Quantity per 1.7-ton batch	Treatment cost, $/1.7-ton batch
INDIRECT COSTS			
Living expenses			
Per diem	Three at $122/day		366.00
Auto rental	Two at $25/day		50.00
Total indirect operating costs per batch			416.00
Indirect operating cost per ton			244.71

[a] All PEG-400 used during the Guam demonstration was purchased at $45.14/100 lb. As of 8/22/88, price of PEG-400 was $101/100 lb.

[b] All KOH used during the Guam demonstration was in pellet form and was purchased at $61.50/100 lb. As of 8/22/88, price of KOH was $66/100 lb.

[c] All sulfuric acid used during the Guam demonstration was purchased at $11.33/100 lb. As of 8/22/88, the price was unchanged.

[d] Fuel oil, electricity, and water were provided by the U.S. Navy at no charge. Costs have been included to provide comparison for a site where these utilities are not provided.

NOTE: $0.0901/kWh is actual electrical usage charge quoted by NCEL.
$1.00/gal fuel oil is estimated.

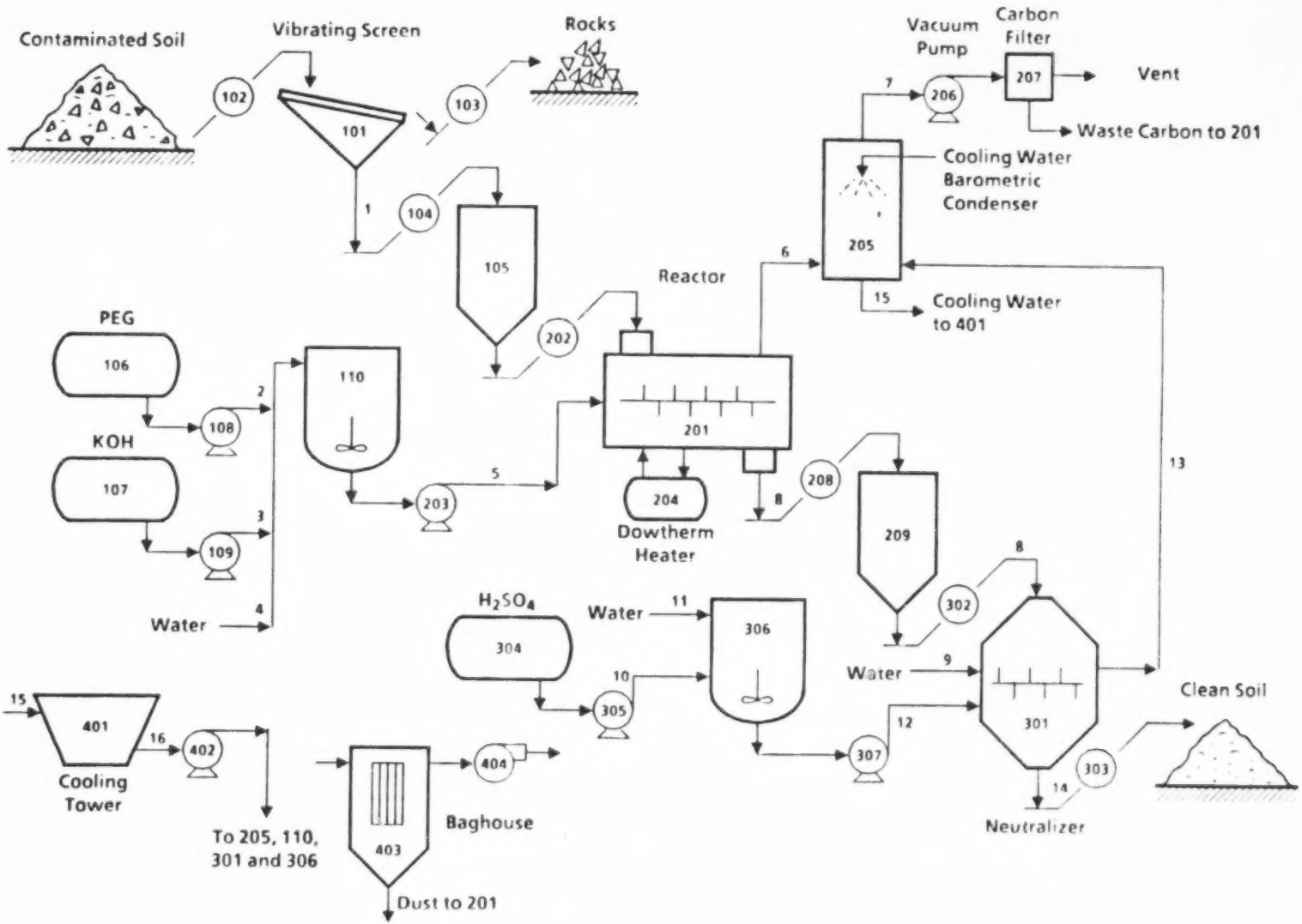


Figure 12. Flowsheet of scale-up KPEG process.

45 percent potassium hydroxide solution is transferred (109) from a storage tank (107) to the KPEG charge tank and mixed with PEG. Water is also added to the KPEG charge tank to obtain the desired KPEG feed composition.

9.2.1.2 Reactor Section (200)--

The KPEG reaction is carried out in a cylindrical mixer-type batch reactor (201), which is equipped with a mechanical agitator. Heat-transfer fluid flows through a jacket around the shell and also through a hollow passage inside the agitator. The reactor is charged by transferring the soil from the charge hopper (105) on a conveyor (202) and by pumping (203) the KPEG solution from the charge tank (110) into the reactor. The four stages of the reaction processes are 1) initial heat-up to bring the reactant temperature from approximately 20° to 100°C, 2) removal of water by evaporation at approximately 100°C, 3) final heat-up of the reactants from 100°C to approximately 150°C, and 4) holding the reactants at approximately 150°C for 4 to 5 hours to complete the reaction. The reactor is heated by a Dowtherm heater (204). Vacuum is applied by the vacuum pump (206) to aid in the water removal. Noncondensable gases exhausted from the reactor are passed through an activated carbon filter (207) before being discharged into the atmosphere. After the reaction is completed, the reaction products are discharged on a conveyor (208) and transferred to a surge hopper (209). Spent activated carbon is blended with influent soil for treatment.

9.2.1.3 Neutralization Section (300)--

The excess potassium hydroxide contained in the reaction product is neutralized with sulfuric acid. Neutralization is carried out in a batch conical vacuum mixer (301). The mixer is equipped with an agitator, and the shell is jacketed for cooling. Additional cooling is provided by evaporation of water from the reactants. The neutralization process is carried out in two steps: 1) the KPEG reaction products, which are still hot (around 150°C), are cooled down to approximately 80°C by spraying water and evaporating the water from the solids; and 2) after solids are cooled down, sulfuric acid is added. Sulfuric acid is fed as a solution (approximately 50 percent) to provide additional water for evaporative cooling to remove heat of neutralization. The temperature is maintained at approximately 80°C during the neutralization process. The moisture content of the soil is maintained at approximately 20 percent to provide sufficient vapor pressure and to obtain the desired evaporative cooling. The sulfuric acid feed system consists of a storage tank (304) for 100 percent acid, a transfer pump (305), a sulfuric acid feed preparation tank (306), and a feed pump (307). Water vapor generated by evaporative cooling is removed with the same vacuum system used during the operation of the KPEG reactor. After the neutralization reaction is completed, the solids are discharged from the neutralizer and transported on a conveyor (303) to a treated soil storage pile.

9.2.1.4 Ancillaries Section (400)--

Cooling water used in the barometric condenser, the KPEG reactor, and the neutralizer is supplied from a cooling tower (401). Fugitive dusts generated around the vibrating screen and conveyors are collected by hoods and removed in a baghouse (403). All water streams are recycled, which results in zero discharge. The baghouse dust is blended into the influent soil for treatment.

9.2.2 Material and Heat Balances

Calculations of material and heat balances were based on a 25-ton batch of screened soil (moisture-free basis). The following assumptions were made:

1) Composition of the KPEG solution at 100 lb PEG, 200 lb KOH, and 1000 lb water/ton of dry soil.

2) Efficiency of the Dowtherm heater (absorbed duty/fuel input) at 85 percent.

3) Heat loss in the KPEG reactor at 25 percent (i.e., 75 percent of the heat transferred from the Dowtherm fluid is absorbed by the reactants).

Composition and temperature of process streams are given in Table 20. Estimated heating and cooling loads are presented in Table 21.

9.2.3 Cost Estimation

Preliminary cost estimates for the KPEG process were calculated by Battelle based on a plant with a treatment capacity of 25 tons (50,000 lb) per batch of soil (dry basis). Table 22 lists equipment costs by process sections. These costs were obtained from published data and vendors. The total equipment cost was estimated to be $1,922,700 (1988 dollars). The KPEG reactor, the most costly item, amounts to approximately 50 percent of the total equipment cost. The fixed capital investment was estimated by a ratio method. Based on the ratio factors shown in Table 23, the fixed capital investment was estimated to be $6,650,000.

The estimated operating cost was based on the following assumptions:

1) Plant operating schedule: 3 shifts/day, 5 days/wk, 40 wk/yr

2) Reactor operating schedule: 12 hours/batch (2 hours for loading and unloading reactor, 1 hour for initial heat-up from 20° to 100°C, 4 hours for evaporation of water, 1 hour for final heat-up from 100° to 150°C, and 4 hours at 150°C); 25 tons/batch (i.e., 50 tons/day or 10,000 tons/yr throughput).

3) Neutralizer operating schedule: 4 hours/batch (2 hours for loading and unloading reactor and 2 hours for reaction), 12.5 tons/batch.

Table 24 presents the itemized operating costs. The treatment cost without profit is estimated to be $347/ton of soil. Table 25 presents a breakdown of the treatment cost. Chemicals and capital-related charges account for 84 percent of the total cost. Potential areas of process improvement are 1) reducing the PEG consumption, and 2) substituting KOH with NaOH. The treatment cost could be reduced by $64/ton by reducing the PEG consumption from 5 percent to 1 percent of the soil. The treatment cost also could be reduced by $41/ton by substituting NaOH for KOH. Adoption of both options

TABLE 20. PROCESS FLOW STREAM COMPOSITION AND TEMPERATURE

Basis: 25-ton batch reactor

Stream No.	Quantity, lb (except as noted)												Temp., °F
	Soil	Liquid H_2O	Vapor H_2O	PCB	PEG	KOH	ROK	KCl	PCB-OR	H_2SO_4	K_2SO_4	Air	
1	50,000	-	-	100	-	-	-	-	-	-	-	-	68
2	-	-	-	-	2500	-	-	-	-	-	-	-	68
3	-	6,111	-	-	-	5000	-	-	-	-	-	-	68
4	-	18,889	-	-	-	-	-	-	-	-	-	-	85
5	-	25,000	-	-	2500	5000	-	-	-	-	-	-	120
6	-	-	25,113	-	-	-	-	-	-	-	-	500[a]	212
7	-	-	11	-	-	-	-	-	-	-	-	500[a]	100
8	50,000	-	-	-	-	4649	2620	20	198	-	-	-	302
9	-	14,180	-	-	-	-	-	-	-	-	-	-	85
10	-	-	-	-	-	-	-	-	-	4061	-	-	68
11	-	4,608	-	-	-	-	-	-	-	-	-	-	68
12	-	4,608	-	-	-	-	-	-	-	4061	-	-	120
13	-	-	7,780	-	-	-	-	-	-	-	-	200[b]	176
14	50,000	12,500	-	-	-	-	2620	20	198	-	7218	-	176
15	-	2,000 gpm	-	-	-	-	-	-	-	-	-	-	95
16	-	2,000 gpm	-	-	-	-	-	-	-	-	-	-	85

[a] Based on 50 lb/h of air leakage over 10 hours into the KPEG reactor.

[b] Based on 50 lb/h of air leakage over 4 hours into the neutralization reactor.

TABLE 21. HEATING AND COOLING REQUIREMENTS

Basis: 25-ton batch reactor

	Total, 10^6 Btu	Time, h	Total, 10^6 Btu/h
Heating of KPEG reactor			
Batch heated from from 20° to 100°C (68° to 212°F)	5.48	1	5.48
Water evaporated at 100°C (212°F)	25.11	4	6.28
Batch heated from 100° to 150°C (212° to 302°F)	3.43	1	3.43
Batch held at 150°C (302°F)	2.00	4	8.00
Cooling of neutralization reactor[a]			
Batch cooled down from 150° to 80°C (302° to 176°F)	1.68	2	0.84
KOH neutralized at 80°C (176°F)	6.10	2	3.05

[a] Neutralization is carried out in two batches of 12.5 tons/batch.

TABLE 22. ESTIMATED EQUIPMENT COST FOR 25-TON KPEG SOIL TREATMENT PLANT

Equipment number	Equipment description	Number of units	Purchase cost, 1988 $	Reference
	Section 100: Feed Preparation			
101	Vibrating screen	1	11,400	a
102	Belt conveyor	1	30,000	a
103	Belt conveyor	1	30,000	a
104	Belt conveyor	1	12,100	a
105	Soil charge hopper (c.s.)[b]	1	34,500	c
106	PEG storage tank (c.s.)	1	7,900	a
107	KOH (45%) storage tank (c.s.)[d]	1	14,300	a
108	PEG transfer pump (c.s./s.s.)	1	3,200	a
109	KOH transfer pump (c.s./s.s.)	1	3,300	a
110	KPEG charge tank with agitator (c.s.)	1	21,500	a
		Section 100	168,200	
	Section 200: KPEG Reactor			
201	KPEG reactor (c.s.)	1	1,000,000	e
202	Belt conveyor	1	12,100	a
203	KPEG feed pump (c.s./s.s.)	1	3,600	a
204	Dowtherm heater package system	1	90,000	f
205	Barometric condenser (c.s.)	1	10,000	a
206	Vacuum pump	1	8,100	g
207	Carbon filter	1	500	
208	Belt conveyor	1	12,100	a
209	Surge hopper (c.s.)	1	34,500	c
		Section 200	1,170,900	
	Section 300: Neutralization			
301	Conical vacuum mixer (Carpenter 20)	1	375,000	e
302	Belt conveyor	1	12,100	a
303	Belt conveyor	1	30,000	a
304	Acid storage tank (s.s.)	1	21,500	a
305	Acid transfer pump (Worthite)	1	4,000	a
306	Acid feed tank with agitator (s.s.)	1	21,500	a
307	Acid feed pump (Worthite)	1	4,000	a
		Section 300	468,100	

(continued)

TABLE 22 (continued)

Equipment number	Equipment description	Number of units	Purchase cost, 1988 $	Reference
	Section 400: Ancillary Equipment			
401	Cooling tower	1	54,300	a
402	Cooling water pump (c.s.)	1	9,800	a
403	Baghouse	1	51,400	a
		Section 400	115,500	
		Plant Total	1,922,700	

[a] Peters and Timmerhaus 1980.

[b] (c.s.) = continuously stirred.

[c] Guthrie 1970.

[d] (c.s./s.s.) = continuously stirred/stainless steel constructon.

[e] Paul O. Abbe 1989.

[f] Uniflux Heaters 1989.

[g] Nash Engineering 1985.

TABLE 23. RATIO FACTOR USED IN ESTIMATING FIXED CAPITAL INVESTMENT FOR KPEG PROCESS

Item	Percent of equipment cost
Direct costs	
Purchased equipment	100
Installation	39
Instrumentation and controls	13
Piping (installed)	31
Electrical (installed)	10
Service facilities	30
Total direct plant cost	223
Indirect costs	
Engineering and supervision	32
Construction expenses	34
Total indirect plant cost	66
Contractor's fee, 5 percent of total direct and indirect plant cost	14
Contingency, 15 percent of total direct and indirect plant cost	43
Fixed capital investment	346

TABLE 24. ESTIMATED TREATMENT COST FOR KPEG PROCESS

Basis: 25-ton batch reactor, 2 batches/day,
3 shifts/day, 5 days/wk, 40 wk/yr
Fixed capital investment = $6,650,000

Item	Unit cost, $	Units/ton soil	Treatment cost, $/ton soil
Chemicals			
PEG	0.80/lb	100	80.00
KOH (45%)	0.145/lb	444	64.38
H_2SO_4(100%)	0.040/lb	162	6.48
Activated carbon	1.00/lb	0.12	0.12
			150.98
Utilities			
Electricity	0.05/kwh	140	7.00
Fuel oil	6.00/10^6 Btu	1.33	5.94
Water	0.50/1000 gal	Nominal	Nominal
			12.94
Labor			
Operators	3/shift, $15/h, 2080 h/yr		28.08
Site manager	1/day, $60/h, 2080 h/yr		12.48
			40.56
Capital-related charges			
Maintenance and repairs, 10% of FCI/yr			66.50
Operating supplies, 15% of M&R			9.98
Depreciation, 10% of FCI/yr			66.50
			142.98
Total cost (without profit or out-of-town crew)			$347.46/ton
Potential cost savings			
Reducing KPEG consumption to 1%			64.00/ton
Substituting NaOH for KOH			41.20/ton
Potential cost after savings			$242.26/ton

could reduce the cost to $242/ton. Other cost savings may be possible through an improved design based on further optimization and pilot testing.

TABLE 25. BREAKDOWN OF TREATMENT COST

Basis: 25-ton batch reactor

Cost item	Percent of total cost
Chemicals	43.4
Utilities	3.7
Labor	11.7
Capital-related	41.2
Total	100.0

Figure 13 shows the effect of the KPEG reactor batch size on treatment cost. The treatment cost without profit increases from $242 to $347/ton at a 25-ton batch size, to between $302 and $407/ton at a 15 ton-batch size, and to between $534 and $639/ton at a 5-ton batch size. The fixed capital investment, however, decreases from $6,650,000 at a 25-ton batch size to $4,895,000 at a 15-ton batch size and to $2,532,000 at a 5-ton batch size.

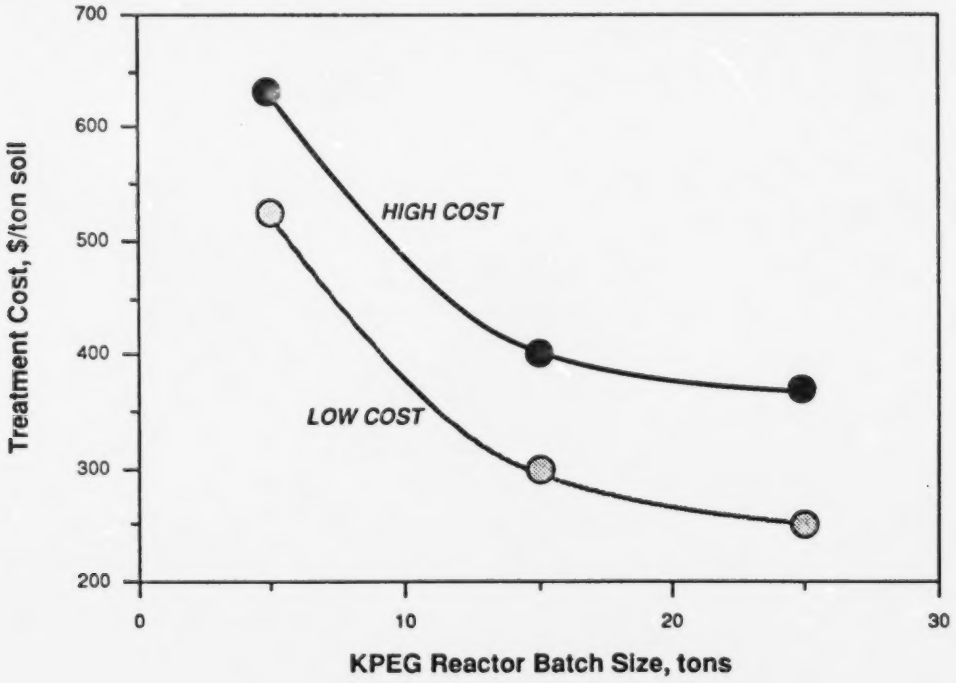


Figure 13. Reactor batch size vs. treatment cost.

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TABLE A-1. PCB INITIAL CALIBRATION SUMMARY FOR HRGC/LRMS

PEI - GUAM

05/24-25/88

CONGENER	CAL SOLUTION #1			CAL SOLUTION #2			CAL SOLUTION #3			CAL SOLUTION #4			CAL SOLUTION #5			X	% RSD
Mono	1.24	1.29	1.22	1.19	1.16	1.20	1.24	1.37	1.24	1.22	1.36	1.16	....	....	....	1.24	5.72
^{13}C-Mono	0.98	1.02	0.95	1.03	1.00	1.02	0.95	1.04	0.94	....	....	....	....	....	....	0.99	3.86
Di	0.96	1.10	0.96	0.89	0.88	0.89	0.93	1.01	0.92	0.90	0.98	0.82	....	....	....	0.94	7.74
Tri	0.65	0.72	0.66	0.62	0.60	0.61	0.64	0.72	0.63	0.61	0.69	0.57	....	....	....	0.64	7.33
Tetra	0.35	0.38	0.36	0.37	0.35	0.36	0.39	0.43	0.39	0.39	0.43	0.35	0.34	0.35	0.34	0.37	7.88
^{13}C-Tetra	0.36	0.38	0.38	0.40	0.39	0.40	0.40	0.41	0.39	....	....	....	....	....	....	0.39	3.85
Penta	0.30	0.31	0.30	0.30	0.30	0.30	0.35	0.38	0.34	0.34	0.35	0.31	0.30	0.30	0.29	0.32	8.42
Hexa	0.22	0.22	0.22	0.23	0.22	0.23	0.25	0.27	0.26	0.26	0.26	0.23	0.22	0.23	0.22	0.24	7.81
Hepta	0.21	0.20	0.20	0.20	0.19	0.20	0.22	0.24	0.22	0.23	0.24	0.21	0.20	0.20	0.19	0.21	7.85
Octa	0.22	0.23	0.21	0.22	0.22	0.22	0.26	0.28	0.25	0.26	0.27	0.23	0.23	0.23	0.21	0.24	9.45
^{13}C-Octa	0.19	0.20	0.20	0.20	0.20	0.21	0.22	0.24	0.22	....	....	....	....	....	....	0.21	7.36
Nona	0.20	0.20	0.19	0.20	0.20	0.20	0.22	0.23	0.22	0.22	0.23	0.20	0.21	0.22	0.19	0.21	6.50
Deca	0.18	0.18	0.16	0.17	0.17	0.18	0.19	0.20	0.19	0.19	0.20	0.17	0.18	0.18	0.16	0.18	6.96
^{13}C-Deca	0.097	0.10	0.093	0.095	0.094	0.096	0.099	0.11	0.099	....	....	....	....	....	....	0.098	5.16

CC1 = Concentration calibration solution #1 = .25 ng/ul for natives; 0.10 ng/ul for ^{13}C-Mono & Tetra; 0.20 ng/ul for ^{13}C-Octa & Deca
CC2 = Concentration calibration solution #2 = 1.0 ng/ul for natives; 0.50 ng/ul for ^{13}C-Mono & Tetra; 1.0 ng/ul for ^{13}C-Octa & Deca
CC3 = Concentration calibration solution #3 = 2.5 ng/ul for natives; 1.0 ng/ul for ^{13}C-Mono & Tetra; 2.0 ng/ul for ^{13}C-Octa & Deca
CC4 = Concentration calibration solution #4 = 5.0 ng/ul for natives
CC5 = Concentration calibration solution #5 = 10.0 ng/ul for natives

ds(980)

TABLE A-2. PCB CONTINUING CALIBRATION SUMMARY

PEI GUAM

Batch 1140

Congener	Multipoint mean RF	Dates 05/26/88 starting	Dates 05/26/88 ending
^{13}C-Mono (% Rec.)	0.99	0.97	0.91
^{13}C-Tetra (% Rec.)	0.39	0.36	0.33
^{13}C-Octa (% Rec.)	0.21	0.19	0.17
^{13}C-Deca (% Rec.)	0.098	0.081	0.073
Mono	1.24	1.20	1.12
Di	0.94	0.82	0.83
Tri	0.64	0.62	0.60
Tetra	0.37	0.35	0.33
Penta	0.32	0.29	0.27
Hexa	0.24	0.22	0.20
Hepta	0.21	0.20	0.18
Octa	0.24	0.22	0.20
Nona	0.21	0.19	0.16
Deca	0.18	0.15	0.13
ds(970)			

TABLE A-3. PCB CONTINUING CALIBRATION

PEI GUAM

Batch 1153

Congener	Multipoint mean RF	Dates					
		05/27/88 starting	05/27/88 ending	05/30/88 starting	05/30/88 ending	06/07/88 starting	06/08/88 ending
^{13}C-Mono (% Rec.)	0.99	1.00	0.91	0.96	0.96	0.86	0.80
^{13}C-Tetra (% Rec.)	0.39	0.35	0.35	0.34	0.34	0.31	0.30
^{13}C-Octa (% Rec.)	0.21	0.20	0.18	0.19	0.18	0.23	0.22
^{13}C-Deca (% Rec.)	0.098	0.086	0.081	0.086	0.092	0.096	0.089
Mono	1.24	1.26	1.10	1.22	1.21	1.09	0.99
Di	0.94	0.86	0.76	0.80	0.87	0.86	0.76
Tri	0.64	0.62	0.53	0.58	0.58	0.59	0.61
Tetra	0.37	0.35	0.31	0.35	0.33	0.29	0.26
Penta	0.32	0.29	0.27	0.28	0.27	0.31	0.29
Hexa	0.24	0.22	0.23	0.22	0.21	0.25	0.24
Hepta	0.21	0.20	0.18	0.21	0.20	0.23	0.21
Octa	0.24	0.22	0.21	0.22	0.21	0.28	0.25
Nona	0.21	0.19	0.17	0.19	0.19	0.23	0.21
Deca	0.18	0.16	0.14	0.16	0.16	0.17	0.16
ds(970)							

TABLE A-4. PCB CONTINUING CALIBRATION

PEI GUAM

Batch 1154

Congener	Multipoint mean RF	Dates			
		05/26/88 starting	05/26/88 ending	06/07/88 starting	06/08/88 ending
^{13}C-Mono (% Rec.)	0.99	0.97	0.91	0.86	0.80
^{13}C-Tetra (% Rec.)	0.39	0.36	0.33	0.31	0.30
^{13}C-Octa (% Rec.)	0.21	0.19	0.17	0.23	0.22
^{13}C-Deca (% Rec.)	0.098	0.081	0.073	0.096	0.089
Mono	1.24	1.20	1.12	1.09	0.99
Di	0.94	0.82	0.83	0.86	0.76
Tri	0.64	0.62	0.60	0.59	0.61
Tetra	0.37	0.35	0.33	0.29	0.26
Penta	0.32	0.29	0.27	0.31	0.29
Hexa	0.24	0.22	0.20	0.25	0.24
Hepta	0.21	0.20	0.18	0.23	0.21
Octa	0.24	0.22	0.20	0.28	0.25
Nona	0.21	0.19	0.16	0.23	0.21
Deca	0.18	0.15	0.13	0.17	0.16
ds(970)					

TABLE A-5. PCB CONTINUING CALIBRATION

PEI GUAM

Batch 1155

Congener	Multipoint mean RF	Dates			
		06/07/88 starting	06/08/88 ending	06/13/88 starting	06/13/88 ending
^{13}C-Mono (% Rec.)	0.99	0.86	0.80	0.91	0.78
^{13}C-Tetra (% Rec.)	0.39	0.31	0.30	0.41	0.31
^{13}C-Octa (% Rec.)	0.21	0.23	0.22	0.26	0.23
^{13}C-Deca (% Rec.)	0.098	0.096	0.089	0.099	0.081
Mono	1.24	1.09	0.99	1.10	1.00
Di	0.94	0.86	0.76	0.85	0.75
Tri	0.64	0.59	0.61	0.46	0.50
Tetra	0.37	0.29	0.26	0.31	0.30
Penta	0.32	0.31	0.29	0.35	0.33
Hexa	0.24	0.25	0.24	0.27	0.23
Hepta	0.21	0.23	0.21	0.21	0.21
Octa	0.24	0.28	0.25	0.27	0.28
Nona	0.21	0.23	0.21	0.21	0.20
Deca	0.18	0.17	0.16	0.16	0.15
ds(970)					

TABLE A-6. PCB CONTINUING CALIBRATION

PEI GUAM

Batch 1164

Congener	Multipoint mean RF	Dates			
		06/10/88 starting	06/10/88 ending	06/13/88 starting	06/13/88 ending
^{13}C-Mono (% Rec.)	0.99	0.90	0.86	0.92	0.91
^{13}C-Tetra (% Rec.)	0.39	0.36	0.32	0.36	0.41
^{13}C-Octa (% Rec.)	0.21	0.23	0.24	0.26	0.26
^{13}C-Deca (% Rec.)	0.098	0.080	0.091	0.092	0.099
Mono	1.24	1.16	1.10	1.14	1.10
Di	0.94	0.85	0.86	0.89	0.85
Tri	0.64	0.52	0.55	0.49	0.46
Tetra	0.37	0.30	0.29	0.32	0.31
Penta	0.32	0.32	0.33	0.34	0.35
Hexa	0.24	0.26	0.25	0.27	0.27
Hepta	0.21	0.22	0.21	0.22	0.21
Octa	0.24	0.28	0.30	0.29	0.27
Nona	0.21	0.22	0.23	0.22	0.21
Deca	0.18	0.17	0.16	0.16	0.16
ds(970)					

TABLE A-7. PCB CONTINUING CALIBRATION

PEI GUAM

Batch 1165

Congener	Multipoint mean RF	Dates	
		06/13/88 starting	06/13/88 ending
^{13}C-Mono (% Rec.)	0.99	0.92	0.91
^{13}C-Tetra (% Rec.)	0.39	0.36	0.41
^{13}C-Octa (% Rec.)	0.21	0.26	0.26
^{13}C-Deca (% Rec.)	0.098	0.092	0.099
Mono	1.24	1.14	1.10
Di	0.94	0.89	0.85
Tri	0.64	0.49	0.46
Tetra	0.37	0.32	0.31
Penta	0.32	0.34	0.35
Hexa	0.24	0.27	0.27
Hepta	0.21	0.22	0.21
Octa	0.24	0.29	0.27
Nona	0.21	0.22	0.21
Deca	0.18	0.16	0.16
ds(970)			

TABLE A-8. PCB CONTINUING CALIBRATION

PEI GUAM

Batch 1168

Congener	Multipoint mean RF	Dates					
		06/20/88 starting	06/20/88 ending	06/22/88 starting	06/22/88 ending	06/27/88 starting	06/27/88 ending
^{13}C-Mono (% Rec.)	0.99	1.18	1.16	1.14	1.04	1.14	1.15
^{13}C-Tetra (% Rec.)	0.39	0.40	0.43	0.40	0.40	0.45	0.40
^{13}C-Octa (% Rec.)	0.21	0.22	0.20	0.21	0.18	0.17	0.20
^{13}C-Deca (% Rec.)	0.098	0.098	0.11	0.13	0.12	0.070	0.082
Mono	1.24	1.27	1.46	1.43	1.34	1.43	1.51
Di	0.94	0.92	0.95	0.89	0.88	1.06	0.89
Tri	0.64	0.66	0.66	0.70	0.66	0.79	0.69
Tetra	0.37	0.34	0.40	0.40	0.39	0.41	0.38
Penta	0.32	0.33	0.32	0.32	0.33	0.28	0.27
Hexa	0.24	0.26	0.24	0.23	0.21	0.20	0.19
Hepta	0.21	0.22	0.20	0.20	0.19	0.15	0.17
Octa	0.24	0.25	0.23	0.20	0.21	0.20	0.22
Nona	0.21	0.24	0.21	0.22	0.19	0.17	0.19
Deca	0.18	0.20	0.21	0.22	0.22	0.14	0.14

ds(982/gen93)

(continued)

TABLE A-8 (continued)

Congener	Multipoint mean RF	Dates	
		06/29/88 starting	06/29/88 ending
^{13}C-Mono (% Rec.)	0.99	1.09	0.96
^{13}C-Tetra (% Rec.)	0.39	0.38	0.39
^{13}C-Octa (% Rec.)	0.21	0.21	0.17
^{13}C-Deca (% Rec.)	0.098	0.11	0.076
Mono	1.24	1.52	1.33
Di	0.94	1.02	0.99
Tri	0.64	0.68	0.67
Tetra	0.37	0.36	0.40
Penta	0.32	0.33	0.32
Hexa	0.24	0.23	0.23
Hepta	0.21	0.20	0.18
Octa	0.24	0.23	0.20
Nona	0.21	0.21	0.15
Deca	0.18	0.19	0.14
ds(982/gen93)			

TABLE A-9. PCB CONTINUING CALIBRATION

PEI GUAM

Batch 1169

Congener	Multipoint mean RF	Dates					
		06/20/88 starting	06/20/88 ending	06/21/88 starting	06/21/88 ending	06/27/88 starting	06/27/88 ending
^{13}C-Mono (% Rec.)	0.99	1.18	1.16	1.12	1.17	1.14	1.15
^{13}C-Tetra (% Rec.)	0.39	0.40	0.43	0.41	0.45	0.45	0.40
^{13}C-Octa (% Rec.)	0.21	0.22	0.20	0.20	0.20	0.17	0.20
^{13}C-Deca (% Rec.)	0.098	0.098	0.11	0.12	0.12	0.070	0.082
Mono	1.24	1.27	1.46	1.38	1.48	1.43	1.51
Di	0.94	0.92	0.95	0.84	0.95	1.06	0.89
Tri	0.64	0.66	0.66	0.62	0.66	0.79	0.69
Tetra	0.37	0.34	0.40	0.39	0.44	0.41	0.38
Penta	0.32	0.33	0.32	0.29	0.36	0.28	0.27
Hexa	0.24	0.26	0.24	0.22	0.26	0.20	0.19
Hepta	0.21	0.22	0.20	0.19	0.21	0.15	0.17
Octa	0.24	0.25	0.23	0.22	0.23	0.20	0.22
Nona	0.21	0.24	0.21	0.20	0.22	0.17	0.19
Deca	0.18	0.20	0.21	0.21	0.23	0.14	0.14

TABLE A-10. PCB CONTINUING CALIBRATION

PEI GUAM

Batch 1179

Congener	Multipoint mean RF	Dates			
		06/27/88 starting	06/27/88 ending	06/29/88 starting	06/29/88 ending
^{13}C-Mono (% Rec.)	0.99	1.14	1.15	1.09	0.96
^{13}C-Tetra (% Rec.)	0.39	0.45	0.40	0.38	0.39
^{13}C-Octa (% Rec.)	0.21	0.17	0.20	0.21	0.17
^{13}C-Deca (% Rec.)	0.098	0.070	0.082	0.11	0.076
Mono	1.24	1.43	1.51	1.52	1.33
Di	0.94	1.06	0.89	1.02	0.99
Tri	0.64	0.79	0.69	0.68	0.67
Tetra	0.37	0.41	0.38	0.36	0.40
Penta	0.32	0.28	0.27	0.33	0.32
Hexa	0.24	0.20	0.19	0.23	0.23
Hepta	0.21	0.15	0.17	0.20	0.18
Octa	0.24	0.20	0.22	0.23	0.20
Nona	0.21	0.17	0.19	0.21	0.15
Deca	0.18	0.14	0.14	0.19	0.14
ds(982)					

TABLE A-11. QA/QC REPORT, BATCHES 1164, 1165 (SAMPLES BB0432 AND BB0433)

Relative percent difference	Sample Nos. BB0432 and BB0433									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Jar (a) =	ND	0.18	ND	0.52	ND	0.31	ND	ND	ND	ND
Soxhlet (b) =	ND	0.46	0.084	1.4	ND	0.53	ND	ND	ND	ND
% RPD = $\frac{\lvert a-b \rvert}{\frac{a+b}{2}} \times 100\%$ =	--	88%	--	92%	--	52%	--	--	--	--

TABLE A-12. QA/QC REPORT, BATCHES 1154, 1155 (SAMPLES BB0434 AND BB0435)

Relative percent difference	Sample Nos. BB0434 and BB0435									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Jar (a) =	ND	1.7	ND	15.7	300.	1400	1100	170.	8.4	ND
Soxhlet (b) =	ND	ND	ND	14.4	238.	1760	1310	225.	8.6	ND
% RPD = $\frac{\lvert a-b \rvert}{\frac{a+b}{2}} \times 100\%$ =	--	--	--	8.6%	23%	23%	17%	28%	2.3%	--

TABLE A-13. QA/QC REPORT, BATCHES 1154, 1155 (SAMPLES BB0436 AND BB0437)

Relative percent difference	Sample Nos. BB0436 and BB0437									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Jar (a)	ND	1.2	ND	15.5	367.	1830	1390	214.	10.1	ND
Soxhlet (b)	ND	ND	ND	8.8	293.	1940	1460	239.	11.2	ND
% RPD = $\frac{\lvert a-b \rvert}{\frac{a+b}{2}} \times 100\%$ =	--	--	--	55%	22%	5.8%	4.9%	11%	10%	--

TABLE A-14. QA/QC REPORT, BATCHES 1164, 1165 (SAMPLES BB0438 AND BB0439)

Relative percent difference	Sample Nos. BB0438 and BB0439									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Jar (a) =	ND	ND	ND	2.4	1.6	7.3	ND	ND	ND	ND
Soxhlet (b) =	ND	0.41	0.15	3.4	3.0	9.0	0.59	ND	ND	ND
% RPD = $\frac{\lvert a-b \rvert}{\frac{a+b}{2}} \times 100\%$ =	--	--	--	34%	61%	21%	--	--	--	--

TABLE A-15. QA/QC REPORT, BATCH 1140 (SAMPLE BB0407)

Extraction efficiency	Sample No. BB0407									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
1st Extraction (a)	ND	1.0	ND	28.3	486.	2200	1660	270.	13.9	ND
2nd Extraction (b)	ND	0.011	ND	0.19	3.3	14.5	10.6	1.9	0.11	ND
Efficiency = $\frac{a}{a+b}$ x 100% =	..	99%	..	99%	99%	99%	99%	99%	99%	..

TABLE A-16. ANALYTICAL RESULTS OBTAINED FOR TWO POSTTREATMENT SOILS AND ONE CONDENSATE SAMPLE AND MATRIX SPIKES

	Final soil	Matrix spike	Condensate	matrix spike	Final soil	Matrix spike
Client No.	G511B1PNS	G511B1PNS	G516B6C	G516B6C	G510B3PNS	G510B3PNS
IT No.	BB0438-R[a]	BB0438MS[a]	BB0482[b]	BB0482MS[b]	BB0485[a]	BB0485MS[a]
CONGENER						
^{13}C-Mono (% Rec.)	80	82	137	128	95	102
^{13}C-Tetra (% Rec.)	91	103	145	109	182	147
^{13}C-Octa (% Rec.)	111	116	93	68	74	88
^{13}C-Deca (% Rec.)	111	84	122	74	105	97
Mono	ND(0.045)	1.2	ND(22.5)	131.	0.053	1.8
Di	ND(0.24)	0.83	50.9	153.	0.56	1.4
Tri	ND(0.37)	0.75	ND(32.3)	ND(128.)	ND(0.17)	0.95
Tetra	2.4	2.9	499.	786.	2.1	3.1
Penta	1.6	2.7	3,370	3,010	ND(0.22)	1.0
Hexa	7.3[b]	7.9	4,400	4,520	0.15	0.97
Hepta	ND(0.14)	1.2	777.	1,000	ND(0.22)	1.1
Octa	ND(0.60)	1.0	43.7	118.	ND(0.37)	0.75
Nona	ND(0.17)	0.90	ND(2.2)	57.4	ND(0.074)	0.95
Deca	ND(0.11)	0.76	ND(3.8)	62.2	ND(0.094)	1.1

[a] Reported in ppm.

[b] Reported in ppb.

TABLE A-17. QA/QC REPORT, BATCH 1164 (SAMPLE BB0438)

Accuracy of spike	Sample No. BB0438									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Orig. Value (a) =	ND	ND	ND	2.4	1.6	7.3	ND	ND	ND	ND
Observed Spike Value (b) =	1.2	0.83	0.75	2.9	2.7	7.9	1.2	1.0	0.90	0.76
Spike Level (c) =	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Accuracy = $\frac{b-a}{c}$ x 100% =	120%	83%	75%	50%	110%	60%	120%	100%	90%	76%
EPA Range =	a	a	a	a	a	a	a	a	a	a

[a] Range established in QAPP Section 3 page 2 as 20 to 150%.

TABLE A-18. QA/QC REPORT, BATCH 1168 (SAMPLE BB0482)

Accuracy of spike	Sample No. BB0482									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Orig. Value (a) =	ND	50.9	ND	499.	3370	4400	777.	43.7	ND	ND
Observed Spike Value (b) =	131.	153.	ND	786.	3010	4520	1000	118.	57.4	62.2
Spike Level (c) =	100	100	100	100	100	100	100	100	100	100
Accuracy = $\frac{b-a}{c}$ x 100%	131%	102%	0%	287%	360%	120%	223%	74%	57%	62%
Range =	a	a	a	a	a	a	a	a	a	a

[a] Range established in QAPP Section 3 page 2 as 20 to 150%.

TABLE A-19. QA/QC REPORT, BATCH 1169 (SAMPLE BB0485)

Accuracy of spike	Sample No. BB0485									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Orig. Value (a) =	0.053	0.56	ND	2.1	ND	0.15	ND	ND	ND	ND
Observed Spike Value (b) =	1.8	1.4	0.95	3.1	1.0	0.97	1.1	0.75	0.95	1.1
Spike Level (c) =	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Accuracy = $\frac{b-a}{c} \times 100\%$ =	175%	84%	95%	100%	100%	82%	110%	75%	95%	110%
Range =	a	a	a	a	a	a	a	a	a	a

[a] Range established in QAPP Section 3 page 2 as 20 to 150%.

TABLE A-20. COMPARISON OF GUAM SOIL PRIOR TO AND AFTER KPEG TREATMENT

Batch No.	Aroclor prior to treatment, ppm	Residual PCB uncorrected, ppm	Corrected
1	1990	tetra-Cl BP = 2.11 penta-Cl BP = 5.42 hexa-Cl BP = 7.33	2.24 6.46 6.50
2	1740	tetra-Cl BP = 1.87	1.99
3	1490	tetra-Cl BP = 1.36	1.45
4	1540	tetra-Cl BP = 1.82	1.94
5	1010	tetra-Cl BP = 1.80	1.91
6	1410	tetra-Cl BP = 4.12	4.38
7	1140	tetra-Cl BP = 3.27	3.48
8	1860	tetra-Cl BP = 4.64	4.94

AKornel:bk:CBDB:7517

TABLE A-21. COMPARISON OF RESULTS GENERATED IN EPA LAB-GUAM AND IT LAB-KNOXVILLE, TENNESSEE (ppm)

Batch number	EPA Lab Aroclor in ppm prior to treament	IT Lab Aroclor in ppm prior to treament	Relative percent difference
1	1990	2996	43%
2	1740	3828	75%
3	1490	3406	78%
4	1540	3778	96%
5	1010	3651	113%
6	1410	3041	73%

Batch number	EPA Lab Aroclor in ppm after treament	IT Lab Aroclor in ppm after treament	Relative percent difference
1	15.2	11.3	29.4%
2	1.99	1.01	65.3%
3	1.45	2.86	66%
4	1.94	3.7	64%
5	1.91	3.5	62%
6	4.38	7.77	56%

TABLE A-22. QA/QC REPORT - SURROGATE PERCENT RECOVERY SUMMARY - PRETREATMENT SOILS

Project Name - PEI GUAM - Code ITEC25534

	^{13}C-Mono	^{13}C-Tetra	^{13}C-Octa	^{13}C-Deca
Number of Data Points	10	10	10	10
Mean Percent Recovery	82%	82%	93%	138%
Range	78 - 89%	76 - 94%	82 - 115%	117 - 184%
Standard Deviation	3%	6%	12%	22%

TABLE A-23. QA/QC REPORT - SURROGATE PERCENT RECOVERY SUMMARY - POST-TREATMENT SOILS

Project Name - PEI GUAM - Code ITEC25534

	^{13}C-Mono	^{13}C-Tetra	^{13}C-Octa	^{13}C-Deca
Number of Data Points	6	6	6	6
Mean Percent Recovery	87%	126%	104%	84%
Range	80 - 95%	86 - 182%	74 -116%	53 - 111%
Standard Deviation	7%	39%	15%	24%

TABLE A-24. QA/QC REPORT - SURROGATE PERCENT RECOVERY SUMMARY - RECOVERED KPEG REAGENT

Project Name - PEI GUAM - Code ITEC25534

	^{13}C-Mono	^{13}C-Tetra	^{13}C-Octa	^{13}C-Deca
Number of Data Points	3	3	3	3
Mean Percent Recovery	102%	100%	88%	122%
Range	91 - 120%	86 - 122%	83 - 97%	108 - 123%
Standard Deviation	16%	19%	8%	13%

TABLE A-25. QA/QC REPORT - SURROGATE PERCENT RECOVERY SUMMARY - COLLECTED CONDENSATE

Project Name - PEI GUAM - Code ITEC25534

	^{13}C-Mono	^{13}C-Tetra	^{13}C-Octa	^{13}C-Deca
Number of Data Points	12	12	12	12
Mean Percent Recovery	105%	113%	90%	117%
Range	77 - 142%	76 - 179%	68 - 110%	74 - 163%
Standard Deviation	25%	29%	12%	21%

TABLE A-26. QA/QC REPORT - SURROGATE PERCENT RECOVERY SUMMARY - TREATED SOIL/RECOVERED REAGENT MIXTURE

Project Name - PEI GUAM - Code ITEC25534

	^{13}C-Mono	^{13}C-Tetra	^{13}C-Octa	^{13}C-Deca
Number of Data Points	5	5	5	5
Mean Percent Recovery	101%	133%	90%	89%
Range	92 - 129%	100 - 174%	78 - 98%	79 - 103%
Standard Deviation	16%	31%	7%	10%

TABLE A-27. PCB DATA SUMMARY - DUPLICATE ANALYSIS OF SPLIT SAMPLE
PEI - GUAM (ppm)

Congener	Client G512B5S1, IT BB0442	Client G512B5S1, IT BB0443
^{13}C-Mono (% Rec.)	80	80
^{13}C-Tetra (% Rec.)	90	91
^{13}C-Octa (% Rec.)	87	86
^{13}C-Deca (% Rec.)	125	121
Mono	ND(0.038)	ND(0.044)
Di	2.0	1.7
Tri	ND(1.5)	ND(0.68)
Tetra	22.0	22.7
Penta	355	398
Hexa	1650	1770
Hepta	1280	1360
Octa	205	214
Nona	9.6	10.9
Deca	ND(0.64)	ND(0.29)
Total PCB	3523.8	377.3

Relative Percent Difference = 6.9%

TABLE A-28. QA/QC REPORT, BATCH 1153 (SAMPLE BB0452)

Precision of duplicate injection	Sample No. BP0452									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Value (b) =	ND	19.8	ND	122	1060	2170	124	ND	ND	ND
Dup. Inj. Value (a) =	ND	17.8	ND	97	967	2430	158	ND	ND	ND
Precision = $\frac{\lvert a-b \rvert}{\frac{a+b}{2}} \times 100\%$ =	--	11%	--	23%	9.2%	11%	24%	--	--	--
Range =	a	a	a	a	a	a	a	a	a	a

[a] Range established in QAPP Section 3 page 2 as 40%.

TABLE A-29. QA/QC REPORT, BATCH 1154 (SAMPLE BB0446)

Precision of duplicate injection	Sample No. BB0446									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Value (b) =	ND	2.0	ND	21.1	360	1480	1010	160	7.8	ND
Dup. Inj. Value (a) =	ND	1.6	ND	17.3	348	1700	1200	201	10.3	ND
Precision = $\frac{\lvert a-b \rvert}{\frac{a+b}{2}} \times 100\%$ =	--	22%	--	20%	3.4%	14%	17%	23%	28%	--
Range =	a	a	a	a	a	a	a	a	a	a

[a] Range established in QAPP Section 3 page 2 as 40%.

TABLE A-30. QA/QC REPORT, BATCH 1155 (SAMPLE BB0437)

Precision of duplicate injection	Sample No. BB0437									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Value (b) =	ND	ND	ND	5.4	293.	1940	1460	239.	11.2	ND
Dup. Inj. Value (a) =	ND	ND	ND	12.2	323.	1790	1250	245.	7.5	ND
Precision = $\frac{\lvert a-b \rvert}{\frac{a+b}{2}} \times 100\%$ =	--	--	--	77%	9.7%	8.0%	15%	2.5%	40%	--
Range =	a	a	a	a	a	a	a	a	a	a

[a] Range established in QAPP Section 3 page 2 as 40%.

TABLE A-31. QA/QC REPORT, BATCH 1168 (SAMPLE BB0476)

Precision of duplicate injection	Sample No. BB0476									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Value (b) =	ND	819.	ND	3150	30200	62600	17000	1460	ND	ND
Dup. Inj. Value (a) =	ND	506.	ND	3740	28600	63800	17900	1520	ND	ND
Precision = $\frac{\lvert a-b \rvert}{\frac{a+b}{2}} \times 100\%$ =	--	47%	--	17%	5.4%	1.9%	5.2%	4.0%	--	--
Range =	a	a	a	a	a	a	a	a	a	a

[a] Range established in QAPP Section 3 page 2 as 40%.

TABLE A-32. QA/QC REPORT, BATCH 1169 (SAMPLE BB0478)

Precision of duplicate injection	Sample No. BB0478									
	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca
Value (b) =	0.075	0.86	ND	2.6	ND	ND	ND	ND	ND	ND
Dup. Inj. Value (a) =	0.065	0.60	ND	2.4	ND	ND	ND	ND	ND	ND
Precision = $\frac{\lvert a-b \rvert}{\frac{a+b}{2}} \times 100\%$ =	14%	36%	--	8.0%	--	--	--	--	--	--
Range =	a	a	a	a	a	a	a	a	a	a

[a] Range established in QAPP Section 3 page 2 as 40%.

TABLE A-33. PCB DATA SUMMARY - REAGENT BLANKS IN SODIUM SULFATE, PEI - GUAM
(ppb)

Client No.		RB	RB	RB	RB	RB	RB
IT No.	BLK1140	BLK1154	BLK1155	BLK1164	BLK1165	BLK1169	BLK1179
^{13}C-Mono (% Rec.)	26	34	71	70	89	104	86
^{13}C-Tetra (% Rec.)	30	59	69	82	93	112	129
^{13}C-Octa (% Rec.)	27	79	97	101	118	84	88
^{13}C-Deca (% Rec.)	35	130	141	75	101	108	87
Mono	ND(0.091)	ND(0.30)	ND(0.36)	ND(0.39)	ND(0.33)	ND(0.48)	ND(0.35)
Di	1.4	ND(2.5)	ND(1.4)	ND(2.8)	ND(2.0)	2.5	2.0
Tri	ND(1.9)	ND(1.4)	ND(38.3)	ND(3.0)	ND(83.0)	ND(3.0)	ND(2.2)
Tetra	ND(0.73)	ND(2.4)	ND(1.6)	ND(1.0)	ND(1.5)	ND(34.9)	ND(0.80)
Penta	ND(1.8)	ND(2.3)	ND(8.5)	ND(3.1)	ND(27.9)	ND(8.9)	ND(2.9)
Hexa	ND(0.36)	ND(1.1)	ND(1.3)	ND(1.2)	ND(1.5)	ND(1.9)	ND(1.3)
Hepta	ND(0.42)	ND(0.44)	ND(1.5)	ND(0.60)	ND(1.8)	ND(1.1)	ND(3.2)
Octa	ND(3.9)	ND(6.4)	ND(2.7)	ND(6.8)	ND(7.0)	ND(9.5)	ND(7.6)
Nona	ND(0.24)	ND(0.48)	ND(1.7)	ND(0.85)	ND(0.78)	ND(1.3)	ND(2.0)
Deca	ND(0.32)	ND(0.60)	ND(1.2)	ND(0.74)	ND(0.59)	ND(1.7)	ND(0.92)

TABLE A-34. PCB DATA SUMMARY REAGENT BLANKS IN DEIONIZED WATER
PEI - GUAM
[ppt (pg/g)]

Client No. IT No.	RB BLK1153[a]	RB BLK1168[a]
CONGENER		
^{13}C-Mono (% Rec.)	40	89
^{13}C-Tetra (% Rec.)	80	116
^{13}C-Octa (% Rec.)	74	98
^{13}C-Deca (% Rec.)	141	125
Mono	ND(1.2)	ND(4.1)
Di	13.9	17.4
Tri	ND(9.8)	ND(31.2)
Tetra	ND(7.3)	ND(8.7)
Penta	ND(8.8)	ND(269.)
Hexa	ND(6.4)	ND(14.3)
Hepta	ND(106.)	ND(11.4)
Octa	ND(2.1)	ND(77.3)
Nona	ND(2.5)	ND(8.1)
Deca	ND(1.8)	ND(11.4)

TABLE A-35. CONCENTRATIONS OF TETRACHLORINATED THROUGH OCTACHLORINATED PCDD AND PCDF FOUND IN GUAM SOILS
(nanograms per gram of sample or ppb)

Sample No.	Tetra CDFs	Tetra CDDs	Penta CDFs	Penta CDDs	Hexa CDFs	Hexa CDDs	Hepta CDFs	Hepta CDDs	Octa CDF	Octa CDD
7A	8.93	ND[a]	1.44	ND	0.0333	ND	ND	ND	ND	0.307
		0.0133		0.0186		0.0365	0.0177	0.0175	0.0340	
7D	3.09	ND	1.38	ND	0.0247	ND	ND	ND	ND	0.379
		0.0132		0.0125		0.0341	0.0181	0.0165	0.0432	
8B	29.8	ND	3.80	ND	ND	ND	ND	ND	ND	ND
		0.0178		0.0267	0.0275	0.0605	0.0258	0.0434	0.0678	0.0717
8D	1.42	ND	0.269	ND	ND	ND	ND	ND	ND	ND
		0.0205		0.0312	0.0233	0.0223	0.0373	0.0552	0.0727	0.0869
LAB BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	0.0039	0.0089	0.0043	0.0125	0.0117	0.0203	0.0084	0.0111	0.0444	0.0259

[a] ND indicates "None Detected" in excess of the minimum detectable concentration that is listed directly below the ND designation

TABLE A-36. RESULTS OF GC/MS ANALYSES OF EXTRACTS FOR 2,3,7,8-TCDD
(nanograms per gram of sample or ppb)

Sample No.	Weight, g[a]	DB5 column isomer-specific analysis: 2,3,7,8-TCDD conc. found, ppm		Instr. ID	Date	Time	Ion int. ratios: 320/322	332/334	% rec.[c]	Ion intensities[d]: 320	322	257	332	334
		Meas.	MDC[b]											
7A	3.560	ND	0.0269	MS25	03/13/89	12:49	-	0.79	69	2300	2335	-1	1008358	1274112
7D	3.100	ND	0.0182	MS25	03/14/89	16:55	-	0.79	95	628	833	-1	407028	513165
8E	2.680	ND	0.0178	MS25	03/13/89	17:04	-	0.80	35	-1379	-1218	-3683	1202768	1509064
8D	2.680	ND	0.0261	MS25	03/14/89	15:09	-	0.80	56	490	490	-1	290900	365880
LAB BLANK	3.000	ND	0.0193	MS25	03/14/89	13:28	-	0.81	95	675	1211	1661	633434	786605

a. For water samples the weight of the sample aliquot was calculated by multiplying the volume of water analyzed by 1.0000.

b. MDC = Minimum Detectable Concentration

c. % Rec. = Percent recovery for the TCDD internal standard

d. The notation used here to designate ion intensities is exponential notation.
A negative sign preceding the peak intensity value cited indicates that no response was observed at that m/z.

TABLE A-37. RESULTS OF GC/MS ANALYSES OF EXTRACTS FOR 2,3,7,8-TCDF
(nanograms per gram of sample or ppb)

Sample No.	Weight, g[a]	DB5 column nonisomer-specific analysis: 2,3,7,8-TCDF conc. found, ppb		Instr. ID	Date	Time	Ion int. ratios: 304/306	312/	% rec.[c]	Ion intensities[d]: 304	306	241	312
		Meas.	MDC[b]										
7A	3.560	0.942	-	MS25	03/13/89	12:49	0.81		75	137369	168887	56579	1494252
7D	3.100	0.230	-	MS25	03/14/89	16:55	0.75		118	12972	17215	4952	693021
8B	2.680	3.47	-	MS25	03/13/89	17:04	0.77		42	486610	634444	176215	1972440
8D	2.680	0.0948	-	MS25	03/14/89	15:09	0.70		69	3137	4507	1842	492065
LAB BLANK	3.000	ND	0.0054	MS25	03/14/89	13:28	-		61	240	953	-1	554671

a. For water samples the weight of the sample aliquot was calculated by multiplying the volume of water analyzed by 1.0000.

b. MDC = Minimum Detectable Concentration

c. % Rec. = Percent recovery for the TCDF internal standard

d. The notation used here to designate ion intensities is exponential notation.
A negative sign preceding the peak intensity value cited indicates that no response was observed at that m/z.

TABLE A-38. INTERNAL STANDARDS RECOVERIES[a]

Sample No.	%rec TCDF INT	%rec TCDD INT	%rec TCDD SUR	%rec PCDD INT	%rec HXCDD INT	%rec HPCDD INT	%rec OCDD INT	Average % rec
7A	75	69	69	83	88	99	99	83
7D	118	95	94	125	123	125	113	113
8B	42	35	34	50	52	60	56	47
8D	69	56	56	69	69	69	59	64
LAB BLANK	61	95	93	120	117	122	101	101

[a] Wright State University, Dayton, Ohio 45435.

TABLE A-39. CHAIN-OF-CUSTODY FORM FOR SAMPLE ALIQUOTS SUBMITTED FOR PCDD/PCDF ANALYSES

PROJECT NAME/NUMBER Guam/KREG 3711.2.1 LAB DESTINATION Illinois State Univ.

SAMPLE TEAM MEMBERS T. Price, P. Weba, D. Elston, J. Jones CARRIER/WAYBILL NO.

SAMPLE NUMBER	SAMPLE LOCATION AND DESCRIPTION	DATE AND TIME COLLECTED	SAMPLE TYPE	CONTAINER TYPE	CONDITION ON RECEIPT (NAME AND DATE)
7A	HOPPER 7 PRIOR to RETREATMENT	9/13/88 13:00 HR	GRAB	GLASS w/ TEFLON LID	
7D	HOPPER 7 POST NEUTRALIZATION & RETREATMENT	9/23/88 07:00 HR	GRAB	GLASS w/ TEFLON LID	
8B	HOPPER 8 PRIOR TO RETREATMENT	9/13/88 13:00 HR	GRAB	GLASS w/ TEFLON LID	
8D	HOPPER 8 POST RETREATMENT & NEUTRALIZATION	9/24/88 07:00 HR	GRAB	GLASS w/ TEFLON LID	

SPECIAL INSTRUCTIONS: Tetra - Octa Dibenzodioxin & Tetra - Octa Dibenzofuran analyses

POSSIBLE SAMPLE HAZARDS

SIGNATURES: (NAME,COMPANY,DATE,AND TIME) J. L. A. Jones 11/29/88 IEI Assoc.

1. RELINQUISHED BY: J. L. A. Jones

RECEIVED BY: Timothy L. Price 11-28-88

2. RELINQUISHED BY: Timothy L. Price 11/30/88

RECEIVED BY:

3. RELINQUISHED BY:

RECEIVED BY:

4. RELINQUISHED BY:

RECEIVED BY: